National Aeronautics and
Space Administration

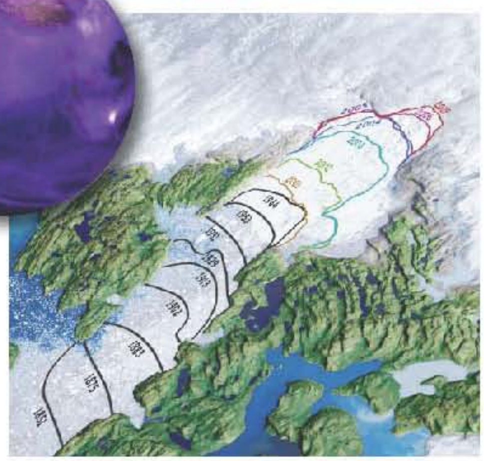
GODDARD SPACE FLIGHT CENTER'S EARTH SCIENCES DIVISION

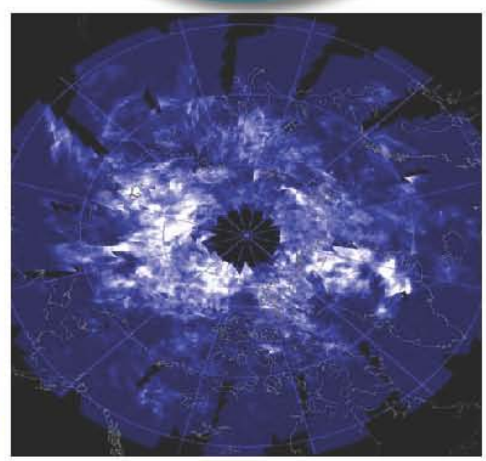
Strategic Plan/Annual Report

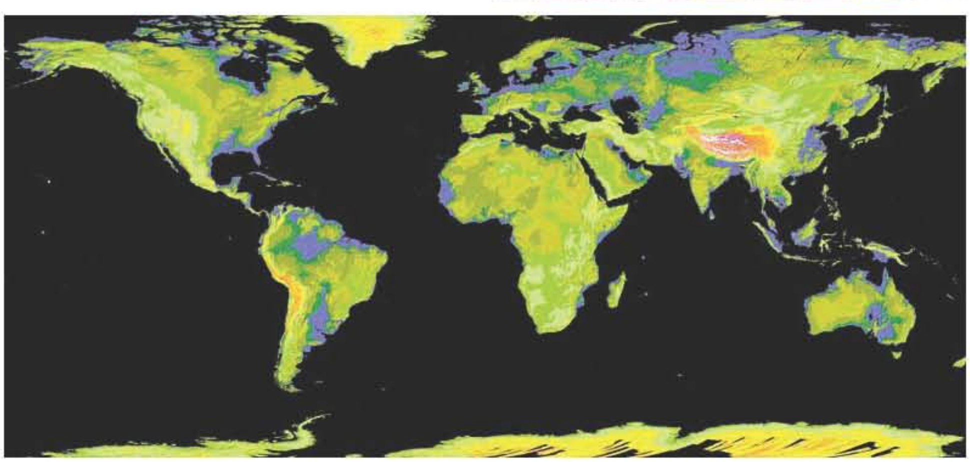
January 2010

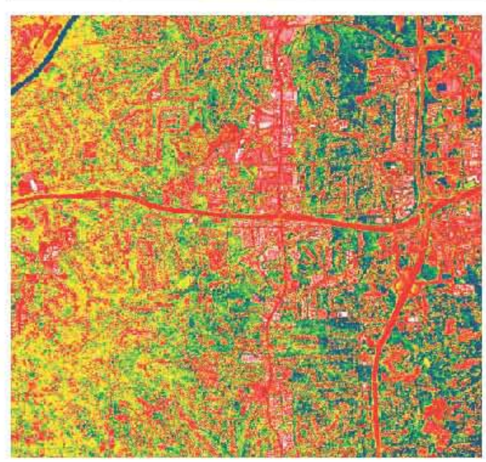
Our Mission

"To Improve Life on Earth and to Enable Space Exploration through the Use of Space-Based Observations"









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Preface

Welcome to the report and strategic plan of the Earth Sciences Division (ESD) at the Goddard Space Flight Center (GSFC). This Division, Code 610, is one of the four Divisions of the Sciences and Exploration Directorate. The others are the Astrophysics Science Division, the Heliophysics Science Division, and the Solar System Exploration Division.

The writing of this report takes place at a particularly interesting and hopeful time for Earth system science. The National Research Council (NRC) report entitled *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, 2007,* and the *Intergovernmental Panel on Climate Change (IPCC) report*, *2007*, have called the attention of the general public as well as the politicians and decision makers to the potential impact of global change on society. Wildfires, floods, droughts, record numbers of tornadoes and events such as Hurricane Katrina, have also reminded everyone that weather can have a major impact on our safety and our economy. One also perceives an increased sensitivity to the opinion of the international community in recognition that our science deals with global problems whose solution requires an international consensus. The recent meeting in Copenhagen, where advanced and developing countries met to discuss measures to reduce the production of CO_2 and other trace gases, confirmed how difficult it is to produce a consensus. The economic and political impact on such measures is enormous within each country as well as internationally. We can anticipate in the months ahead a lively debate within our own country on the effectiveness and costs of the cap and trade program.

Within NASA, we continue to support the implementation of the NRC recommended missions, struggling between mission requirements, costs, and overall budgets.

This document is divided into three parts. The first part is a description of the Division's mission and goals, of our role as a government laboratory in support of the agency programs and of the community at large, of what we do for our science and its applications, and of our commitment to education and public outreach. It describes the organizational structure, processes, and funding sources. It describes its internal components, management challenges and the strategic plan for hiring new people. The second part describes our intellectual foci and strategic plan for our research. Although the overall NASA strategic plan is the responsibility of NASA Headquarters, it behooves us to emphasize the areas on which we want to focus our energies and capabilities. The third part includes the Appendices, which contain a variety of statistics concerning our performance as scientists and members of our research community.

At some level this document is also an implementation plan. It provides a sanity check on the strategic plan elements. Documents of this kind require a fair amount of work, but they are useful.

As Dwight D. Eisenhower once wrote *"… I have always found that plans are useless, but planning is indispensable."*

The important part of generating this document is not the plan itself but the concentrated focus by the authors on what the vision of ESD will be and how we are going to carry it out. The strategic plan as a whole will probably have a short lifetime, but elements of the plan and the vision of what we are and what we do will influence our approach to new opportunities and ongoing initiatives beyond the specific plan.

The completion of this report coincides with my retiring from NASA at the end of January 2010. It has been an honor and privilege to have had the opportunity to head the Earth Sciences Division at Goddard, to be the Chief of the Laboratory for Atmospheres, and the Head of the Severe Storms Branch. These organizations have outstanding, dedicated people. I would like to give you two quotes. One from an e-mail I received a couple of years ago from a scientist who decided to stay in the Division after having interviewed for a position in another first-rate organization: "*I came and stayed at Goddard because we do world class science on the large scale for extremely important topics: Science with a capital S. Those things that enable science made me want to stay, while those things that hinder science made me want to leave."* The other quote is from a manager's presentation at a retreat within the last year or so: "*I often tell my staff to think about why we come to work every day: it is no less than to take care of our home planet. GSFC is the best place to do this work, and if we do not do it, who will? "*

I wish the Division good luck with the confidence that it will continue to make important contributions to the science of the Earth system and its applications for the benefit of the Nation.

Many people have contributed to this document. I hesitate to mention them by name for fear of forgetting someone, except for Diane Elben who gently nudged people to submit their contributions, compiled most of the data in the report, and formatted the entire document. To all I express my gratitude.

Franco Einaudi
Director of the Earth Sciences Division

Part I

The Earth Sciences Division

1. Philosophy

As we carry out our work in the Earth Sciences Division, we strive to honor the following values:

Individual Well-being

Personal Freedom
Individuals are encouraged to express their views and to offer diverging opinions. This freedom promotes a sense of openness and responsibility. Science thrives on disagreement.

Programmatic and Research Balance
Our Division often has relatively large programs, sizable satellite missions, or observational campaigns that require the cooperative and collaborative efforts of many scientists. We aim to ensure an appropriate balance between our scientists; responsibility for these large projects and their need for an active individual research agenda. This balance allows members of the Division to continuously improve their scientific credentials.

Research Quality

The Division places high importance on promoting and measuring quality in its scientific research. We strive to assure high quality through peer-review funding processes. The overall quality of our scientific efforts is evaluated periodically by committees of advisors from the external scientific community such as the Global Modeling and Assimilation Office (GMAO) Advisory Board, and the Sciences and Exploration Directorate Visiting Committee.

Scientific Partnerships

Synergy between Science and Technology
The Division aims to increase its interaction with the Applied Engineering and Technology Directorate (AETD) through the formation of joint teams to develop new technologies and engineering solutions for scientific questions.

Goddard offers enormous opportunities for synergy between engineering and scientific expertise. Experimental activities are spread across the Division to foster communication and to maximize the direct application of technology to scientific goals. Healthy collaboration between our scientists and the Center's engineers is vital to our success in the competitive research environment in which we operate.

Interaction with Other Scientific Groups
The Division depends on collaboration with the academic community, with other NASA Centers and Federal laboratories, and with foreign agencies. Section 5 discusses some of these relationships more fully. The Division has Memorandums of Understanding (MOUs) with a number of universities for cooperative science programs, and we have close ties with universities in Maryland through three centers: Goddard Earth Science and Technology (GEST) Center with the University of Maryland, Baltimore County (UMBC), the Joint Center for Earth Systems Technology (JCET) with UMBC, and the Earth System Science Interdisciplinary Center (ESSIC) with the University of Maryland College Park. The Division also has a close relationship with Howard University.

Support for Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers, the project manager, and the project scientist, who are the principal leaders of project management and science respectively.

The project scientist must provide continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Taking on the responsibilities of a project scientist provides a unique opportunity for Division staff to obtain significant scientific management experience. Typically, the Division invites candidates from the senior ranks to fill these roles.

Outreach and Education

Members of the Division interact with the general public to support a wide range of interests in the science areas.

Among other activities, the Division raises the public's awareness of Earth system science by presenting public lectures and demonstrations, by making scientific data available to wide audiences, by teaching, and by mentoring students and teachers. The Division has close collaborations with the Office of Public Affairs.

Human Resources

The Division is committed to addressing the demographic imbalances that exist today in the atmospheric and space sciences. We must address these imbalances for our field to enjoy the full benefit of the entire Nation's talent. To this end, the Division always seeks qualified women and underrepresented ethnic groups when hiring new scientists and technologists.

Opportunities for the Commercial Sector

The Division fully supports government/industry partnerships, Small Business Innovative Research (SBIR), and technology transfer activities.

2. The NASA Vision and Mission

The definition of the NASA vision, mission, scientific and application goals, and attendant space missions is the responsibility of NASA Headquarters (HQ).

<u>NASA's Science Vision</u>

The scientific exploration of our planet, other planets and planetary bodies, our star system in its entirety, and the universe beyond.

<u>NASA's Mission</u>

To pioneer the future in space exploration, scientific discovery, and aeronautics research.

<u>NASA's Earth Science Division Strategic Goal</u>

Study Earth from space to advance scientific understanding and meet societal needs.

To achieve the Earth sciences goal, the Science Mission Directorate (SMD) at NASA HQ has identified six interdisciplinary Science Focus areas:

- Atmospheric Composition
- Carbon Cycle and Ecosystems
- Climate Variability and Change
- Earth Surface and Interior
- Water and Energy Cycle
- Weather

NASA missions and associated research have many applications to societal needs. NASA HQ has identified seven primary application areas:

- Agriculture
- Air Quality
- Disaster Management
- Ecological Forecasting
- Public Health
- Water Resources
- Weather

NASA brings its unique vantage point of space observations to deal with the major challenge of our time of understanding human influence on climate, of predicting its evolution and its impact on society. By providing substantial assets that include satellite, aircraft, instruments and people, NASA makes major contributions to the national and international strategic Earth science goals as expressed in the report *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, 2007, hereafter referred to as the National Research Council (NRC) Decadal Survey, the *Intergovernmental Panel on Climate Change (IPCC)*, 2007, and the *U.S. Climate Change Science Program (CCSP) Report*, 2008.

3. GSFC Support of National Needs for Earth System Science

The GSFC Earth Sciences Division's (ESD) unique contribution to the advancement of Earth system science is partly the result of its work using the vantage point of space and partly the result of the critical mass of scientists and engineers working across the full range of different disciplines that cover the atmosphere, the biosphere, the cryosphere, the hydrosphere, and the solid Earth. The GSFC environment, where scientists, engineers, and managers all coexist, provides unique opportunities for synergistic interactions.

ESD scientists participate in each step of the following science process, in collaboration with engineers, managers, information technology experts, and with the community:

From Science Requirements to New Missions:

(1) Defining new scientific questions;
(2) Identifying critical new measurements;
(3) Conceiving, formulating, designing, implementing, and participating in day-to-day operations and management of satellite missions (Project Scientist Function);
(4) Developing the instrument technology needed for new observations;
(5) Planning and managing experimental campaigns to validate satellite data and improve our knowledge of the underlying processes;

Creation and Distribution of Data Sets:

(6) Developing algorithms to create data sets;
(7) Developing models to create and interpret data sets;
(8) Developing and operating data processing, archives, and distribution systems that facilitate use of NASA science data;

Optimizing the Use of Satellite Data:

(9) Developing models and data assimilation techniques to optimize the use of satellite data in weather and climate forecasting;
(10) Develop techniques to optimize instrument design and impact on forecasting capabilities;
(11) Analyzing data and models to understand the underlying processes;

Applications:

(12) Developing applications for the benefit of society;

Communication and Education:

(13) Communicating science results for decision makers;
(14) Contributing to the scientific literacy of the general public.

Steps (1) and (2): ESD scientists work with colleagues at universities, other government agencies, NASA HQ, and NASA Centers to formulate the scientific objectives for the Agency.

Steps (3) and (4): Developing instruments and designing missions are core functions of the Center. NASA GSFC's strengths are the technology base for space remote sensing and in-situ measurement capabilities, and the science base for technical development. GSFC scientists and engineers work together in developing new technology and in developing concepts and designs for instrument systems for orbital and sub-orbital missions. GSFC Project Scientists provide scientific guidance to Project Managers while acting as the interface among the instrument Principal Investigators (PIs), NASA HQ, and the scientific community at-large.

Step (5): Planning and managing validation campaigns are significant post-mission launch activities in which ESD is engaged. Remote sensing observations, such as those from satellites, require careful validation. (Validation is the process of proving to the science community that the advertised estimates of measurement precision and uncertainty are correct using correlative measurements.) Intense validation campaigns take place shortly after a satellite is commissioned, but validation activities continue over the course of the mission to ensure that instrumental changes are understood. Validation activities usually involve measurements by ground-based facilities, aircraft, rockets, or balloons during satellite overflights. In coordination with NASA HQ and other NASA Centers, ESD scientists develop validation plans and lead validation missions.

Step (6): Measurement data sets are developed by teams of instrument algorithm specialists, and the creation of long-term highly calibrated data sets is necessary to study the Earth's climate and the variability of the Sun. ESD scientists have proven most effective at the task of converting observed signals (e.g. photon counts at a detector) from space-based instruments into the desired physical quantities. Data reanalysis activities in the U.S. and Europe have shown that inconsistencies in data quality are a large source of uncertainty in the climate record. Some inconsistencies can be traced to changes in sensor calibration, to sensor degradation, and to algorithm changes. Developing long-term data records with high enough quality to be used to detect Earth system changes is an important activity within ESD.

Step (7): Numerical modeling and data assimilation provide the only tools that address the prediction and process definition questions of the NASA Earth science research agenda. Models summarize the theoretical underpinnings of our understanding of the Earth-Sun system, integrating across the timescales and research themes. Data assimilation provides a rigorous method for bringing the observations and models together in a systematic way that balances the information from different sensors and platforms. It also provides information that has not or cannot be observed. Assimilation requires core competencies in all aspects of the Earth system science. ESD scientists are leaders in both global modeling and data assimilation. Among their many activities, they evaluate new methodologies for assimilating data from specific observing systems, and they aid in the design of new observing systems by performing what are known as Observing System Simulation Experiments (OSSEs).

Step (8): Data and information management systems are a critical component to ensure the availability, accessibility, and quality of mission and research science data products. Science leadership coupled with technical expertise in information science, information technology, computing engineering, and in specific scientific disciplines is required to make system design and operation decisions that anticipate and address scientific insights and priorities. Having in-house expertise in these areas reduces data system start-up cost/risk and enables data system evolution to address changing science requirements and priorities.

Step (9), (10), and (11): The utility of satellite data, assimilation products, and global prediction models is not fully realized until they can be combined to further our basic understanding of the Earth system. Satellite data, alone or in combination with assimilation products, must be analyzed to derive information about the modes of variability of the Earth system and the interactions between climate processes and environmental parameters that control the various feedback loops in the system. The knowledge gained is then implemented into the models via improved parameterizations to enhance prediction capabilities. Since many forced and unforced influences may operate simultaneously, innovative approaches must be pursued in developing models and data assimilation techniques, in designing new instruments, in optimizing observational platforms, and ultimately in comparing large data sets and models. As the home to the development of models and assimilation techniques, and the production of data, ESD expertise must serve as an example to the broader community of how to integrate observations, data, and models.

Step (12): Progress in the science of the Earth system results in many applications that benefit society. Weather has long been known to have a major impact on human activities, and more recently, climate change has been recognized as having the potential to seriously affect our societies. ESD scientists are fully engaged in providing NASA's space-based observations and prediction to service providers in government and in the private sector.

Step (13): Earth system science has a lot of applications that can result in substantial societal benefits. Policy makers' decisions are important for the well-being of the environment and have substantial impact on our economy. Many of these decisions are the result of progress in our science. The wisdom of these decisions depends on the accuracy of the information received by the policy makers. We believe that scientists in the Division have the responsibility to communicate in a dispassionate and objective way the results of our scientific investigations to policy makers through official channels as well as to private citizens.

Step (14): The ESD carefully considers its responsibility to contribute to the scientific literacy of the general public. To this end, scientists in the division actively participate in NASA's efforts to serve the formal and informal education communities at all levels, by supporting a number of student programs spanning the full range of the educational spectrum, and by enabling and empowering our communication partners, e.g., museums, science centers, and media providers.

We view our expertise as a national resource that goes far beyond scientists doing only fundamental research in isolation. Our division generally deals with large projects that require the long-term sustained, collaborative efforts of many scientists and engineers. Indeed, large projects, particularly those involving conceptualization and implementation of instrumentation systems, and the long-term delivery of carefully calibrated data sets, are what distinguish the research at federal laboratories from that at universities. The associated interaction is taking place to a degree that is unprecedented in academia or elsewhere, because we at GSFC have a critical mass of scientists across a wide range of disciplines.

4. The Earth Sciences Division Mission and Goals

There are three overarching Earth science questions:

- **How does the Earth work?**
  The Earth is a dynamic planet with a complex system of interacting elements: the atmosphere, the biosphere, the cryosphere, the hydrosphere, and the solid portion of Earth's surface. NASA explores the fundamental nature and interactions of these elements and by so doing we begin to understand how our planet works. Moreover, understanding our own living planet informs NASA's search for life elsewhere.

- **How is the Earth changing?**
  The 4.5 billion year history of planet Earth is marked by tumultuous change, the causes of which are not well understood. NASA seeks to discover what natural and man-made forces are driving today's changes, why they act as they do, and how those forces may alter Earth's environment.

- **How does our changing environment affect life on Earth?**
  Life on Earth is both influenced and shaped by its environment. NASA seeks to understand how different types of change affect life and society. Our ability to understand and anticipate the consequences of change will ultimately determine how society will adapt and thrive.

These questions are naturally linked. The processes involved are global. The answers rely on observations producing long-term data sets, their analysis, and modeling. Space observations have provided the essential global view since the mid-1970s. The third question involves prediction, the true test of our understanding, as well as our role in communicating our results to decision makers.

The Division conducts a broad theoretical and experimental research program to answer these questions.

Its mission and goals are:

The ESD Mission

To improve life on Earth and to enable space exploration through the use of space-based observations.

The ESD Goals

- *Advance understanding of the Earth system through exploration from the vantage point of space.*
- *Improve predictions of the Earth system through measurements and models.*
- *Provide leadership in Earth system science and technology including the development of new instruments, measurement missions, and models.*
- *Establish partnerships to promote Earth science.*
- *Enhance the nation's scientific and technological literacy.*

Our mission and goals provide the strategic foundation for ESD activities. The challenges for our nation are to have an understanding of the Earth system and how it is changing and then to predict changes or likelihood of changes. NASA has made available substantial resources to meet these challenges. These assets are programmatically managed by the Earth Science Division at NASA HQ, but are conceived, designed, implemented, and operationally managed at the various NASA Centers, in collaboration with the academic community and the private sector.

The Goddard Space Flight Center has a broad mix of resources for conceiving and flying satellite missions. GSFC has well-recognized strengths in flight dynamics, engineering, scientific management, data production, and data distribution. GSFC has developed and managed a wide range of missions from large multi-instrument platforms like the Earth Observing System (EOS) Terra, Aqua, and Aura to small single-instrument satellites like the Earth Probe Total Ozone Mapping Spectrometer (TOMS) and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). GSFC has built and managed the series of Landsat missions that have monitored land use and land coverage, and it is now building the Landsat continuity mission. A large number of ESD civil servants function as Principal Investigators and Project Scientists for major satellite efforts. A list of Project Scientists and Deputy Project Scientists is provided in Appendix D.

In order for NASA scientists to function effectively in support of NASA missions, they must maintain their own scientific efforts and continue to publish. First-rate science missions require first-rate scientists and engineers for their conception, design, and implementation. First-rate scientists must be recruited, nurtured, and developed over a number of years to maintain an overall high quality in the work force.

5. Inside the Earth Sciences Division

5.1 What the Earth Sciences Division Does

The purview of the Earth Sciences Division includes:

- The atmosphere
- The biosphere
- The cryosphere
- The hydrosphere

The fifth component of the Earth system, the solid portion of the Earth surface, is studied in the Solar System Exploration Division. Interactions between these components take place at different time scales from a few minutes in cloud evolution to millions or billions of years in tectonic plate motions and solar evolution.

While ESD scientists do research in all the recognized components of the Earth system, they are at the forefront of interdisciplinary science—more and more, we see our planet as one system with the most exciting discoveries occurring at the interfaces between the traditional disciplines.

Major science areas in ESD are shown in Table 1. For each focus area, the table also identifies instruments or space missions presently flying or in development, the latter listed in Appendix A, Table A.1, as well as those recommended by the NRC Decadal Survey, Appendix A, Table A.2. The last column has the corresponding NASA HQ focus areas.

Table 1. ESD Science Focus Areas

Focus Area	Science Questions	Instruments/Space Missions	NASA HQ Focus Areas
Atmospheric Aerosols	• How do aerosols affect regional and climate? • How do aerosols affect the Earth's heat balance? • How do aerosols affect cloud and precipitation? • How do aerosols affect ecosystems? • How do aerosols affect health?	MODIS, OMI, ICESat, CALIPSO, EO-1, ACE, GEOCAPE	Atmospheric Composition

Table 1. ESD Science Focus Areas (continued)

Focus Area	Science Questions	Instruments/Space Missions	NASA HQ Focus Areas
Atmospheric Chemistry	• How do anthropogenic activities impact atmospheric pollution at regional and global scales? • What is the impact of long-range transport of pollutants on local air quality? • How will climate change impact local air quality and how will changes in atmospheric composition influence climate change? • How will the stratospheric cooling associated with climate change impact the spatial extent and recovery of the ozone layer and the Antarctic ozone hole? • Is stratospheric ozone recovering in a manner expected from theoretical predictions? • How well can we predict atmospheric chemical impacts on ozone and climate?	SBUV series, ACE, GEOCAPE, GACM	Atmospheric Composition
Atmospheric Water Cycle	• What are the causes of water cycle variations? • How do clouds, water vapor, and precipitation processes affect regional to global weather and climate? • What changes to the atmospheric water cycle are expected in a warmer global environment, especially events with high impact on society such as hurricanes, floods, drought, and forest fires? • How can we use satellite measurements to better understand the physical processes of the atmospheric water cycle and to provide better representation of these processes in global climate and weather models?	TRMM, GPM, NPP, SMAP, ACE, PATH, 3D-Winds	Water and Energy Cycle

Table 1. ESD Science Focus Areas (continued)

Focus Area	Science Questions	Instruments/Space Missions	NASA HQ Focus Areas
Carbon Cycle and Ecosystems	• How are the Earth's carbon cycle and ecosystem changing? • How will climate change influence carbon cycle, ecosystem sustainability, and biodiversity? What needs to be done: • Document terrestrial and marine ecosystems. • Document land cover and use changes. • Quantify global productivity, biomass, and carbon fluxes. • Improve ecological forecasting and climate change predictions.	Landsat, AVHRR, SeaWiFS, MODIS, ICESat, EO-1, NPP, LDCM, SMAP, ICESat II, DESDynI, ASCENDS, GEOCAPE, ACE, LIST, HyspIRI	Carbon Cycle and Ecosystems
Climate Modeling and Analysis	• What is driving climate change? • How does the Earth system respond to changes in climate and what are the associated feedbacks? • What are the impacts of climate change? • What can humans do to alter the magnitude and direction of climate change?	Glory, GPM, NPP, Landsat, and all recommended missions in the Decadal Study	Climate Variability and Change
Oceanography	• How does the ocean circulation contribute and react to changes in the global climate system? • What is the character and variability of the global ocean biology that is detectable through changes in ocean color? • What is the ocean's physical and biological response to changes in its near surface vertical density gradient?	SeaWiFS, MODIS, ICESat, ICESat II, Landsat, Aquarius, SWOT, ACE, GEOCAPE	Climate Variability and Change
Polar Climate Change	• How will changing ice cover contribute to future sea level and over what time scales? • Will there be catastrophic collapse of the major ice sheets? • What will be the influence of changes in land ice on the climate system, the water cycle, and the biosphere? • How will changes in sea ice affect climate and climate processes?	ICESat, MODIS, SMMR, SSM/I, Landsat, ICESat II, DESDynI, LIST, GRACE II	Climate Variability and Change

Table 1. ESD Science Focus Areas (continued)

Focus Area	Science Questions	Instruments/Space Missions	NASA HQ Focus Areas
Terrestrial Water Cycle	• What are the causes of water cycle variations? • Are variations in the global and regional water cycle predictable? • What is the impact of variations of snowmelt runoff on the availability of fresh water? • How are water and biological cycles linked?	SMMR on Nimbus 7, Landsat, SSM/I, AVHRR, GOES, GRACE, MODIS, AMSR-E, AIRS, SMAP, SWOT, ACE, GRACE II, SCLP	Water and Energy Cycle
Weather and Short-term Climate	What needs to be done here: • Interpret the information that the observations provide regarding the variations in our environment. • Make consistent estimates of the state of the Earth system. • Enhance prediction of our future environment. • Enhance our understanding of the possible link between climate change, hurricanes, and severe storms. • Identify the merits of existing and potential of new observations.	GPM, SMAP, Aquarius, SCLP, NPOESS, NPP, ACE, 3D-Winds, and other missions suggested in the NRC Decadal Survey	Weather

Earth system science has a lot of applications. Weather and climate can affect aviation, air quality, health, transportation, agriculture, fisheries, water, energy, construction, tourism, and many other sectors of the economy. Even modest advances in forecast skill lead to huge economic gains.

ESD members make contributions to each of the seven primary application areas listed in Chapter 2. The types of contributions they make are listed in Table 2, which also identifies our partners and the products we provide them. The interaction with our partners often consists of a joint evaluation of the usefulness of our products, provides important information about what users need, and is an important step in the difficult process of transition from research to operations.

Table 2. Contributions to Primary Application Areas

Application Theme	Areas of Concentration	NASA and Other Sensors/ Satellites Used	Partners Utilizing NASA products
Agriculture	• Development of remote sensing based products to improve estimates of global agricultural production • Drought monitoring and forecasting for agricultural applications • Time series analyses of global crop producing areas	– SPOT VGT – AVHRR – MODIS – Landsat – All of the numerous satellite systems that contribute to the GMAO seasonal forecasts.	– USDA/FAS, – U.S. Drought Monitor and U.S. Drought Outlook (NOAA/NCEP)
Air Quality	• Measurement and modeling of tropospheric aerosols and trace gases • Identification and quantification of natural and anthropogenic emissions sources • Aerosol measurement and modeling to improve weather forecasts and air quality forecasts	– Aura/OMI – TRMM/LIS – MODIS – MISR – CALIOP	– NOAA – NRL – EPA – Atmospheric Science Modeling Division, U.S. EPA, Research Triangle Park, NC – Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC – NOAA NCEP
Disaster Management	• Monitoring and forecasting of global and regional floods and landslides • Development of post event flood maps • Development of NDVI, rainfall, humidity and precipitable water data products for areas under drought and food security risk • Development of environmental data products for use in biological, radiological and/or chemical plume trajectory models • Monitoring, identification, and validation of earthquake and volcanic activity and precursor signals • Global assessment of food security risks and development of drought early warning • Evaluation of applicability of NASA's research products for severe weather warning [e.g., NOAA's Advanced Weather Interactive Processing System (AWIPS)]	– MODIS – Landsat – AMSR-E – TRMM – SRTM – AMSU – AVHRR – Meteosat – MPLNET – CALIPSO – CloudSat	– USDA/FAS – NOAA – USAID – International Red Cross – Pacific Disaster Center – SERVIR – United Nations' World Food Program – NCEP

Table 2. Contributions to Primary Application Areas (continued)

Application Theme	Areas of Concentration	NASA and Other Sensors/ Satellites Used	Partners Utilizing NASA products
Ecological Forecasting	• Invasive Species Forecasting (e.g. Cheat Grass, Africanized Honey Bees) • Time series mapping of vulnerable habitats • Early warning for habitat potentially vulnerable to invasion • Decadal Forest Change algorithms and maps (e.g. Congo Basin)	– MODIS – EO-1 – TRMM – SRTM – AMSR – AMSU – Landsat	– Regional Center for Mapping and Resource Development, Nairobi, Kenya – Disaster Management agencies in Kenya, Tanzania, Uganda, and Ethiopia – U.S. Geological Survey, Bureau of Land Management, National Park Service – USAID/CARPE
Public Health	• Monitoring of environmental factors (e.g., temperature, humidity, precipitation, NDVI anomalies) conducive to the spread of vector-borne diseases • Modeling of disease transmission and life cycle • Development of forecast models, risk maps, and early warning for Malaria and Avian Influenza Pandemic for Southeast Asia • Development of assessment models, risk maps, and early warning for Ebola, Rift Valley Fever and Marburg for Sub-Saharan Africa and Arabian peninsula	– AVHRR – MODIS – Landsat – SRTM – ASTER – TRMM – SRTM – EO-1 – Commercial satellite data – SIESIP portal – Meteosat	– USDA – CDC – WHO – FAO – NASA - SERVIR Africa – Governments: Kenya, Tanzania, South Africa, Madagascar, Yemen – DoD organizations – local public health organizations – DoD – Global Emerging Infections Surveillance and Response System (DoD-GEIS)
Water Resources	• Monitoring, modeling, and forecasting of meteorological and hydrological parameters for improved weather forecasting, water resource management, and drought and flood monitoring • Global data products for snow water equivalence, ground water storage, soil moisture, evapotranspiration, reservoir levels, and runoff data • Water resource forecasts at the regional level (Middle East and North Africa regions)	– MODIS – Landsat – TRMM – GRACE	– NOAA – USAID; – Arab Water Council – NOAA NCDC – U. Nebraska, Lincoln

Table 2. Contributions to Primary Application Areas (continued)

Application Theme	Areas of Concentration	NASA and Other Sensors/ Satellites Used	Partners Utilizing NASA products
Weather	• Development of remote sensing based products to improve numerical weather forecasting • Improved soil moisture and temperature forecasts for agriculture and other applications • Near real-time data on rain rate wave spectra for hurricanes • Climate forecasts for improved management in the energy sector • Development of Space Weather data products and model forecasts • Forecasting of Space Weather impacts (geomagnetically induced currents) on the energy sector	– Imager GOES11 – AMSR-E – MODIS – LASCO/SOHO – MAG/ACE – SWEPAM/ ACE – ISCCP – TRMM – Aura sensors – Aqua sensors	– NOAA – AF Res Lab – DOE – Electric Power Research Institute (EPRI) – North American power utilities (Via EPRI) – PJM Interconnection (operator of world's largest energy market) – Exelon Corporation (fifth largest U.S. electricity generator) – U.S. EPA – CARB

We measure the success of our Division by the usual metrics applied to scientific organizations of this size and breadth. Our average win rate for proposals, based on selections from the period of April 2005 to December 2009, was 41%. As another measure of our engagement with the community, we report in Appendix E the number of field campaigns we have led or participated in and the number of workshops we have sponsored in 2009. Appendix F shows the number of professional awards and honors bestowed on our staff.

5.2 Development and Management of Long-Term Data Sets

Earth and space observing satellites have been flown by NASA since the mid-1970s. After launch, scientists continue to develop algorithms and explore techniques for improving the data obtained from the sensors. This effort often extends well beyond our own satellites and sensors to those launched by other organizations – both domestic and international. In this way, GSFC scientists lead the scientific community in developing a space-based understanding of the Earth and solar environments.

Over time, the collection and reprocessing of the data from these early sensors and the process of combining data from more recent sensors with older data has led to the development of what is called "long-term data sets." The scientific community regards these long-term data sets as an important resource. For example, the column ozone data from the first backscatter ultraviolet (BUV) instrument flown on Nimbus 4 in the mid-1970s combined with the TOMS/SBUV, the NOAA SBUV-2 series, Meteor TOMS, Earth Probe (EP) TOMS, up to the recent Aura Ozone Monitoring Instrument (OMI) has provided the stratospheric community with a near continuous measure of changes in the stratospheric ozone layer.

The development of long-term satellite data sets is time consuming, specialized work. Knowledge of both remote sensing and sensor performance is required, and these data sets also incorporate ground-based measurements. The development of long-term data sets from satellite systems is an appropriate function for NASA, although for some of the Earth science data sets, we expect this activity will eventually transition to NOAA as the National Polar-orbiting Operational Environmental Satellite System (NPOESS) system comes on-line. We view the maintenance and improvement of these data sets as a serious responsibility of ESD and an important service to the community.

Some of the key data sets that ESD maintains and the sensor suites from which the data sets are derived are listed in Chapter 8.5.1.

5.3 Winning New Business and Supporting National Needs

To align Goddard's strategic plans with NASA priorities and with national needs, Goddard has created a new management structure, the Line of Business (LOB). We have four LOBs, one for each division at the Sciences and Exploration Directorate.

The Earth Science LOB (ES LOB) is an organized approach for identifying and prioritizing new opportunities, identifying staffing needs, and for optimizing the utilization of the Internal Research and Development (IRAD) program and other internal sources of discretionary funding. The ES LOB activities have centered on supporting the NRC Decadal Survey missions and on addressing national needs for routine measurements of the Earth's weather and climate from space.

The NRC Decadal Survey mission profile includes 15 missions, divided into three tiers, of which the first tier includes four missions to be launched in the upcoming approximately six-eight years, each with a strong Goddard involvement. Ice, Cloud, and Land Elevation Satellite (ICESat)-II, a follow on to ICESat-I is a Goddard mission. The Soil Moisture Active Passive (SMAP) mission is being led by JPL with Goddard providing the key radiometer system. Those two missions are underway and are not an explicit part of the LOB. The LOB activities for the remaining NRC Decadal Survey Tier-1 missions include the Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission, where Goddard will partner with Langley Research Center; and the Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) Earth crustal deformation and biospheric carbon mass mission, where we will partner with JPL. We are presently working with Langley Research Center and JPL to refine Goddard's role in these two missions along lines best suited to Goddard's strengths and as best possible to fit the mission plans into available resources for the missions.

The NRC Decadal Survey Tier-II missions, to be launched in about a decade, are now getting limited but noticeable funding; the Tier-III missions remain mostly in conceptualization. For each of these missions, we are developing plans that will maximize appropriate participation in the missions, utilizing application of Goddard's science, engineering, and project management capabilities to best meet mission needs. Our LOB process uses the priorities for all the NRC Decadal Survey missions to set IRAD priorities, and also to make use of other funding opportunities from other NASA development programs such as the Instrument Incubator Proposal (IIP) and the Advanced Technology Initiatives Program (ATIP).

Goddard's ES LOB activities also address national needs for climate observations of the Earth from space. The NASA program of EOS satellites—Aqua, Terra, Aura, ICESAT, and others—provided a substantial basis for documentation and understanding Earth's climate from space. The remarkable success of NASA's EOS research satellites, plus the operational GOES and POES satellites, illustrates a clear national capability to design, build, and operate highly reliable complex satellite systems for measuring Earth's weather and climate. Indeed, the Geostationary Operational Environmental Satellite (GOES), the Polar Operational Environmental Satellites (POES), and EOS satellites together provide a clear model for success of a stable satellite system that functions well, is affordable, and meets national needs for weather and climate observations. For decades, NASA and NOAA have worked efficiently on the design, instrumentation, and operation of the GOES and POES operational weather satellites.

There is no reason to think that a different approach would efficiently serve the needs of the nation, for the needs of a national climate observing system have many conceptual similarities to the weather observations. As a part of our extensive base of experience, GSFC is devoting considerable effort to understanding successful, cost-effective approaches for the architecture of such a system, and for the details of system engineering. The long-standing approach of having NASA be responsible for the technical design, the procurement, and the launch of the national climate observing system is again a tried and true approach that is without any major flaws. The Agency roles and responsibilities are well tested and will work excellently in the future.

Resources Available

- The IRAD program is designed to fund new instruments or research ideas. Proposals are chosen through an internal competitive selection process. The funds are obtained through assessments levied by the Center on business coming from HQ.

- Strategic Science FTEs are funds that the Center invests in activities that are critical to implement the NASA agenda. Typically these FTEs are used for scientists assigned to investigate new ideas for instruments, missions, or topics relevant to the NRC Decadal Survey. Some FTEs are used for supporting new hires, graduate students through the Cooperative Education Program, and civil servants who wish to spend up to one year of sabbatical time at approved academic or government institutions.

The Division maintains its own New Business Committee to periodically seek input for new missions and instruments. For example, it has collected ideas for possible Venture Class Missions, a class of missions that is recommended by the NRC Decadal Survey. Venture Class missions are cost-constrained concepts that either complement the named missions or have their own scientific objectives. Missions that use unmanned aircraft systems (UASs) are included in Venture Class.

The total number of FTEs obtained by the Division to support civil servants through the above activities is included in Chapter 6.4, Figure 4.

5.4 Supporting Mission Planning for HQ

The GSFC Flight Projects Directorate has established an Earth Science Projects Division (ESPD) which has three main functions: (1) to oversee the execution of missions under development, such as the Global Precipitation Measurement (GPM) Mission, (2) to carry out implementation plans for systematic missions that are in formulation, such as SMAP, and (3) to provide feasibility studies for missions recommended by the NRC Decadal Survey and not yet recommended for formulation by HQ. The ESPD is the equivalent of a HQ function located at the Center and is independent of the Center's ES LOB activities.

The ESD provides civil servant scientists support for all three of these functions. The list of Project and Deputy Project scientists is given in Appendix D. ESD provides study leads for some of the decadal study missions.

5.5 Partnerships with the Academic Community and Government Laboratories

Interaction with the national and international scientific community is essential and is an integral part of the Division activities. Scientists in the academic community and in government laboratories at home and abroad are involved in our research activities, ground-based observational programs, aircraft campaigns, and satellite missions. Indeed these programs are often jointly funded by other agencies and co-sponsored by the international community. Our data sets are created with major contributions from the community and serve as a resource for the community.

In addition to individual interactions among scientists, the Division has established research institutes with a number of universities around the country for the purpose of involving first-rate scientists in our research activities. A substantial effort is underway to encourage graduate students to interact with our scientists, use our data sets, and work with our models. More information is available in Appendix B.

5.6 Partnerships with Operational Agencies

The ESD is fully supportive of HQ's goal of optimally exploiting satellite data for operational and application purposes. We recognize the challenge of "Crossing the Valley of Death*," [Research to Operations in Weather Satellites and Numerical Weather Prediction*, *National Research Council,* 2000] a term often used in industry to describe the difficulties of transitioning from research to operations. To address this challenge, we have formed the Joint Center for Satellite Data Assimilation (JCSDA) with NOAA and the Department of Defense (DoD). We recognize the importance of actively cooperating with other operational agencies and transitioning our research techniques and software into decision support tools (see Chapter 5.1).

The ESD is also supporting the SMD's "valley of death" challenge in another way. Can data from operational satellites be used to create research quality data sets for answering climate change questions? ESD is home to several measurement teams that have created long-term data sets from combined research and operational satellites (see Chapter 8.5.1). These measurement teams in ESD are preparing to extend their EOS expertise into the NPOESS Preparatory Project (NPP) and NPOESS era.

An operational agreement exists between the Landsat Project Science Office (LPSO) and the U.S. Geological Survey Earth Resources Observation and Science (EROS) office for the LPSO support of Landsat characterization and calibration operations.

5.7 Education and Public Outreach

Our challenge in Education and Public Outreach (EPO) is to establish the cognitive and technological "bridges" necessary to effectively share the new data and knowledge that we produce in support of NASA's broad EPO portfolio. To meet this challenge, ESD actively participates in, and in many cases leads, NASA's efforts to serve formal and informal education communities, and to provide data and information to all segments of the public. Sharing the new information that the Division generates is a core part of our overall mission. Our public communications emphasize new and compelling Earth system science results, remote sensing data from NASA's space-based missions, and predictive modeling results of the Earth's climate system. Likewise, we recognize that our audiences are diverse in their needs, wants, and expectations for scientific information. Thus, the Division takes a "customer-oriented" approach to education and outreach by tailoring our communications efforts to meet the needs of our targeted audiences, which includes:

- Formal Educators
    - K-12 teachers, students, and trainers of teachers
    - Two-year college faculty
    - Four-year college faculty and students
    - Graduate students
    - Tribal college students
- Informal Educators
    - Museums and Science Centers
    - Interpretive staff at National Parks, Nature Centers, and Zoos
    - Youth Programs (after school programming, Girl Scouts, 4-H, etc.)
    - Citizen Science groups and programs

- Decisions makers (through work with GSFC and HQ offices of congressional affairs)
- General public (through news media, electronic media and special events)

To help inspire, engage, and develop the next generation of Earth scientists, and build an informed citizenry, the ESD is involved in a number of programs and activities, including:

- Undergraduate and graduate summer programs providing opportunity for students and NASA mentors to interact.
- Programs with historically minority colleges and universities.
- Adjunct professorships at colleges and universities.
- Direct support of graduate student research topics that result in mutual advantage to the universities and to the ESD.
- Membership in thesis committees.
- Courses taught by ESD scientists.
- Post-graduate programs.
- Professional development for community college faculty.
- Professional development for Tribal college instructors.
- Professional development programs for K-12 educators.
- Development and distribution of a wide variety of classroom-ready activities.
- Professional development programs for informal educators.
- Development and distribution of a variety of informal education products and programs.
- Formal/Informal education collaboration with museums and science centers.

Further details are given in Appendix B.1.

In recent years the ESD has actively participated in Center-wide collaborative efforts among GSFC's entire education, EPO, and public affairs community. Division EPO staff are members of the Center-wide EPO working groups and the GSFC Education Implementation Team and are also collaborating with the Director's Council on Science on improving communication skills of ESD personnel and increasing the level and opportunities for EPO participation by ESD staff. This collaborative approach has begun to positively affect the reach of the Division's efforts. An example of this approach is the deepening partnerships between Division EPO staff and the GSFC PAO staff associated with press releases, podcasts, etc., and the cross-division planning efforts for the recent SED Science Jamboree and EPO Open House.

Division scientists and engineers, working with the Public Affairs Office and NASA HQ, continue to actively share their knowledge and interest in Earth sciences with the general public by enabling and empowering our communication partners, e.g., museums, science centers, and media providers. Currently the Division makes use of Web-based and multimedia resources as its primary tools for public outreach, as well as partnering with national associations and other federal agencies for delivery of NASA content. These activities are described in Appendix B.2.

5.8 Toward a More Diversified Workforce

The ethnic and racial distribution in the population is evolving rapidly and the majority of the workforce will change by the middle of the century or earlier. It is important that the composition of the Division workforce changes accordingly and that we create a more inclusive environment. We have taken the following steps toward achieving a more diversified workforce:

- We work with universities, primarily Howard University, to attract minorities to our field.
- We run summer programs for undergraduate and graduate students to attract them to our field. Some of the students are women and minorities.
- We use the GSFC Cooperative Education Program for graduate students to attract minorities to our field.

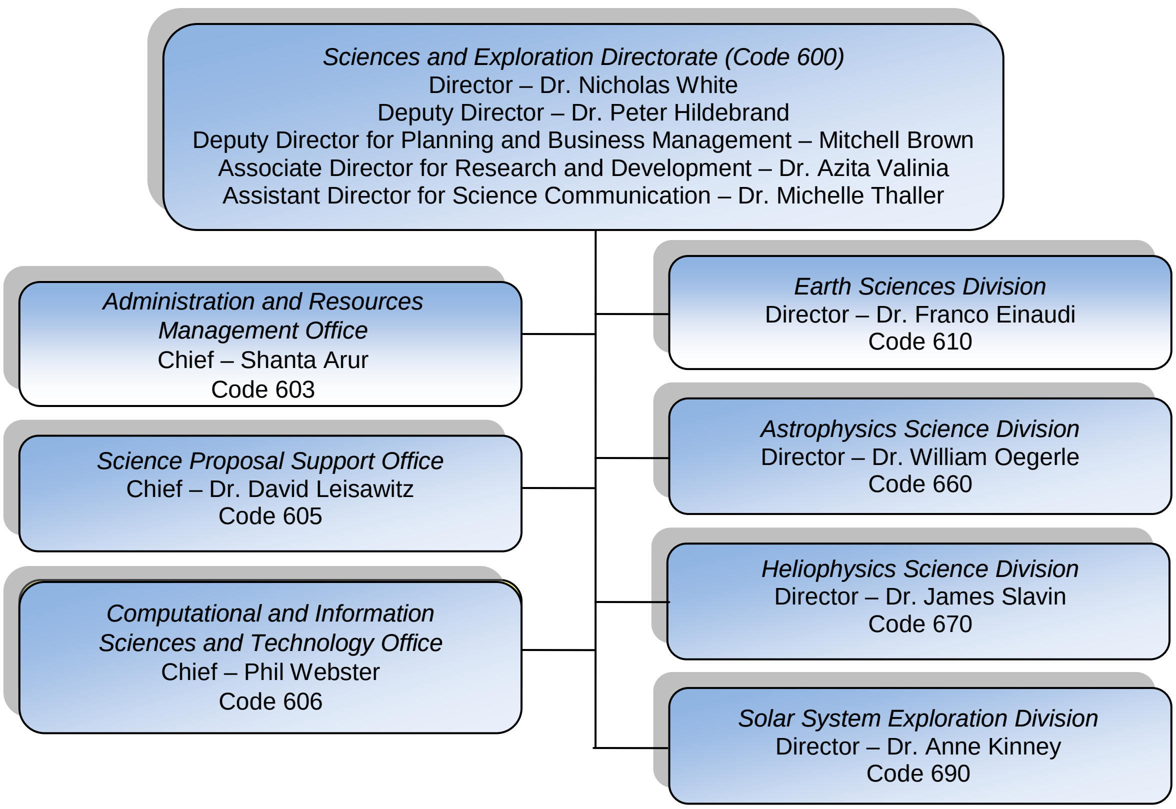
- We are in the process of instituting a mentoring program internal to the Division to help women advance scientifically and professionally in their careers. Bi-weekly luncheons are organized in the Center cafeteria. We will do something similar with underrepresented minorities.
- In the recent and ongoing hiring process, we have advertised in as broad a way as possible. We have hired 2 African-Americans, 1 Hispanic, and 7 women out of a total of 22 new hires.
- We are fully involved with the Directorate Diversity Team whose function is to create a more inclusive and welcoming environment for all our employees.

6. How the Earth Sciences Division Operates

6.1 Organizational and Administrative Structure

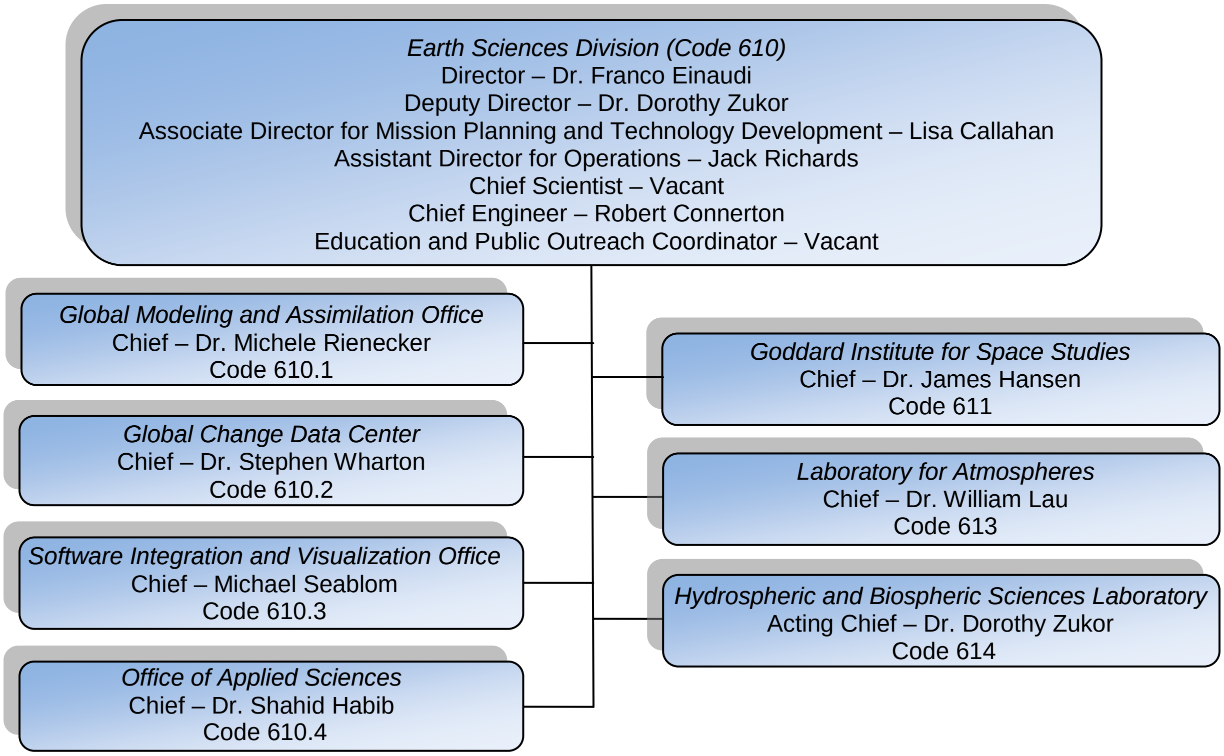
The Earth Sciences Division is one of the four Divisions of the Science and Exploration Directorate (SED). The other three are the Astrophysics Science Division, the Heliophysics Science Division, and the Solar System Exploration Division. The organizational structure is shown next.

Sciences and Exploration Directorate Organization



The Directorate head of SED reports to the GSFC Center Director. This structure roughly mirrors the organization of NASA Headquarters.

Earth Sciences Division
Organization *



***** *A reorganization is in the process of being implemented and it is shown in Appendix G.*

The organizational structures of the Laboratories and Offices are shown in Appendix G. The administration of the ESD is organized according to disciplines—atmosphere, biosphere, hydrosphere, data services, and software services/data visualization. Experimental activities are distributed across the Division. The two Laboratories, the Goddard Institute for Space Studies (GISS), and the Global Modeling and Assimilation Office (GMAO) are predominantly dedicated to research and technology development. The Software Integration and Visualization Office (SIVO) is responsible for advanced software integration, and scientific visualization as a major resource for the Division. The Global Change Data Center (GCDC) leads the development of science data systems for product generation, data management, and distribution for the Division and the Enterprise. The Office of Applied Sciences is responsible for leveraging NASA science products for societal benefit by identifying potential applications of SED science discoveries, scientific observations, data analyses, and technology that could benefit other government agencies, industry, and the public.

6.2 Crosscutting Themes

As mentioned above, the ESD is formally organized around science disciplines and foci of technical expertise. A comprehensive program in the Division, however, requires integration across these discipline-based organizations. The challenges of effective integration are evident on several levels: Lidar technology, for instance, has the potential to provide breakthrough observations in several Earth and space science disciplines, and lidar activities have grown in these disciplines; scientific discovery often resides in taking observations that describe the interaction of parameters that are traditionally studied in their separate disciplines; finally, all aspects of Earth and space science require modeling to analyze observations and to perform predictions. The interdependencies that must be addressed to perform state-of-the-art experiments and to test scientific hypotheses require the consistent consideration of processes that are, again, traditionally studied in their separate disciplines.

A challenge that confronts the ESD is how to promote the integration across Branches and Laboratories. Strategies are required that advance the integration across disciplines, but that at the same time respect and maintain the rapid and productive progress that is made in discipline-based research.

To respond to these challenges, a series of teams were formed for each of the main areas of activities of the Division, often referred to as crosscutting themes. These are interdisciplinary science teams that cut across the disciplinary organization of the Division, described in this chapter. The responsibilities of these teams include: devise research plans across the Division to answer the scientific questions; prioritize areas of activities and identify hiring priorities; work with engineers to develop measuring requirements and formulate mission concepts; work with HQ to maximize the effectiveness of ESD investments; and help HQ to develop and focus their strategic plans and implementation tactics.

Six crosscutting scientific themes have been identified:

Scientific Crosscutting Themes	Lead
Aerosols	Lorraine Remer
Carbon Cycle	G. James Collatz
Clouds and Precipitation	Ann Fridlind, Wei-Kuo Tao, and Steve Platnick
Polar Climate Change	Thorsten Markus
Terrestrial Water	Randy Koster and Christa Peters-Lidard
Weather and Short-term Climate Forecasting	Lars Peter Riishojgaard and Siegfried Schubert

These teams have performed at different levels, with some good successes. An analysis will be carried out to determine their effectiveness and their influence on the management of the Division.

6.3 The Workforce Composition

The composition of the ESD workforce has evolved substantially in the last several years, in part because of the general reduction of the civil servant workforce, and in part in recognition of the scientific advantages of increasing the work done through joint institutes with universities.

The relative composition of the ESD Division is summarized in Figure 1.

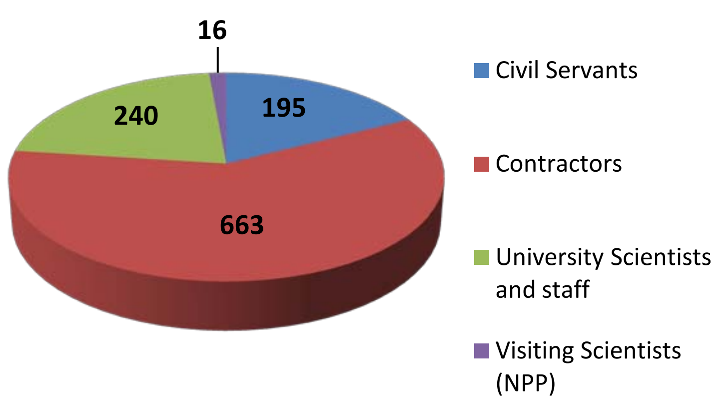


Figure 1. ESD Personnel Composition

The human capital of the ESD includes:

- Civil Servants

  Civil servants are federal employees who are not part of the military. Civil servants are the core research staff in the ESD. This category also includes term appointments which are annual and can be renewed up to six years. At the end of the six years, or earlier, a decision has to be made about converting the position into a permanent one. The ESD currently has 195 civil servants.

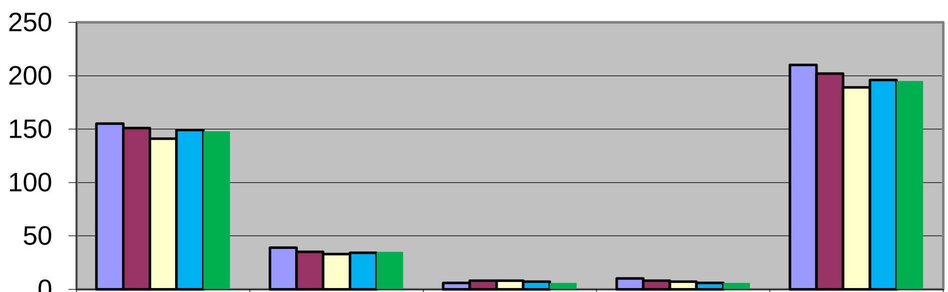
- Scientists from Joint Centers, NASA Postdoctoral Program, etc.

  Most of the non-civil servant scientists come from the Joint Centers that the ESD has established with the University of Maryland at Baltimore County (UMBC), the University of Maryland at College Park (UMCP), George Mason University in Virginia, and Columbia University in New York City. Others are NASA Postdoctoral Program (NPP) Fellows: this is a program for postdoctoral fellows run by the Oak Ridge Associated Universities (formerly run by the National Research Council). Professors on sabbatical or other senior scientists in research organizations are part of the ESD Visiting Fellows Program run by the Goddard Earth Sciences and Technology Center (GEST) at UMBC. Some of the scientists at the Joint Centers develop their own research activities through proposals written to various agencies including NASA, and thus serve as principal investigators who work cooperatively with the civil servants. See Appendix B.

- Contractors

  A major component of the work force is with the private sector. The contractor workforce includes technicians, programmers, information technologists, engineers, and scientists with MS and Ph.D. degrees.

The civil servant skill distribution is described in Figure 2. The figure also provides information about workforce evolution from FY06 till the present.



	Scientist	Engineers	Prof. Admin.	Clericals	Total
FY06	155	39	6	10	210
FY07	151	35	8	8	202
FY08	141	33	8	7	189
FY09	149	34	7	6	196
FY10 to date	148	35	6	6	195

Figure 2. ESD Civil Servant Skill Distribution

6.4 The Funding Sources for the Division

The funding sources for the Division are depicted in Figure 3.

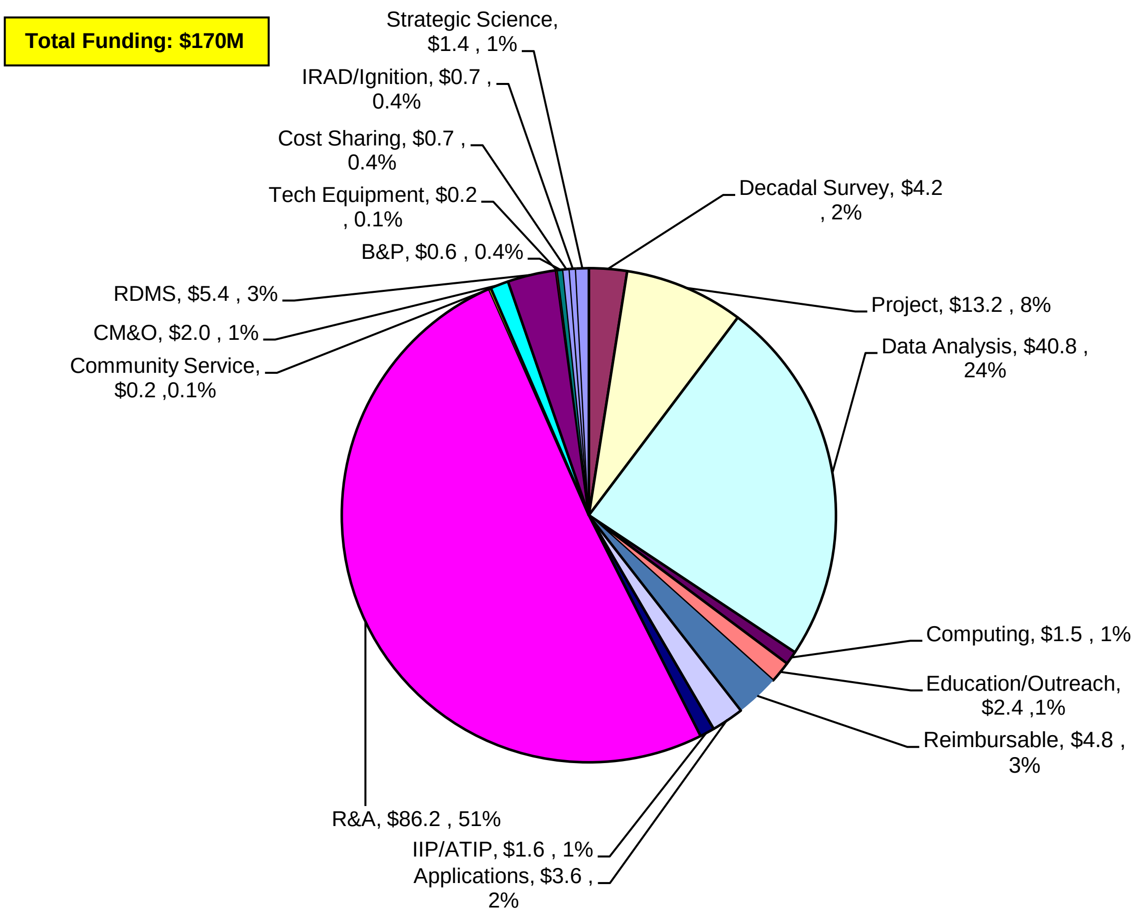


Figure 3. ESD Funding Summary for Fiscal Year 2009 ($M)

The six groups in the figure have the following meaning:

- Research and Analysis (R&A), IIP/ATIP, and Applications:
  - R&A are funds received from HQ through Research Opportunities in Space and Earth Sciences (ROSES) competition.
  - IIP/ATIP are HQ technological programs fully competed.
  - Applications are activities in the area of applications funded by HQ through competition.
- Research and Development Multiple Support (RDMS) and Center Management and Operation (CM&O) cover support for administrative, clerical, and managers (Branch Heads, Laboratory Chiefs, and Division Director), as well as some support for Education and Public Outreach and IT Security. Community Service funds civil servant expertise

when requested by SMD to support peer reviews, advisory groups, roadmap teams, etc. These funds are not competed.

- IRAD/Ignition, Cost Sharing, Tech Equipment, Bid and Proposal (B&P), and Strategic Science are Goddard investments from the Center's CM&O budget to increase our competitiveness in winning proposals.
  - IRAD and Ignition are programs funded by Goddard to carry out primarily technological development. These funds are competed within Goddard.
  - Cost sharing is the Center's contribution to cover a portion of civil servants salaries identified in a proposal. The program will be terminated at the end of FY10.
  - Tech equipment is the Center's strategic contribution for purchasing new laboratory equipment or refurbishing existing laboratory equipment.
  - B&P are funds made available to civil servants to cover their time in writing proposals.
  - Strategic Science is a program funded by GSFC to support important scientific objectives. There is some competition within the Directorate
- Decadal Survey Support:
  - Decadal Survey Support consists of funds received from HQ to study the possible implementation of Decadal Survey missions. These funds are not competed.
- Project and Data Analysis:
  - Projects directly support a number of people involved in the management of the missions (project scientists, associate project scientists, etc.).
  - Data Analysis support refers to activities directly related to the analysis of data obtained for a given mission.
- Computing, Education/Outreach, and Reimbursable:
  - Computing is funds SIVO receives from the GSFC Computational and Information Sciences and Technology Office.
  - Education and Outreach is largely competed.
  - Reimbursable is applied work that we do for other organizations. Proposals are written, but the funding is not usually the result of competition.

Figure 3 includes funds for civil servants salaries, non-civil servant personnel, equipment, and any other activity in the Division.

The funding sources for the civil servant positions are outlined in Figure 4.

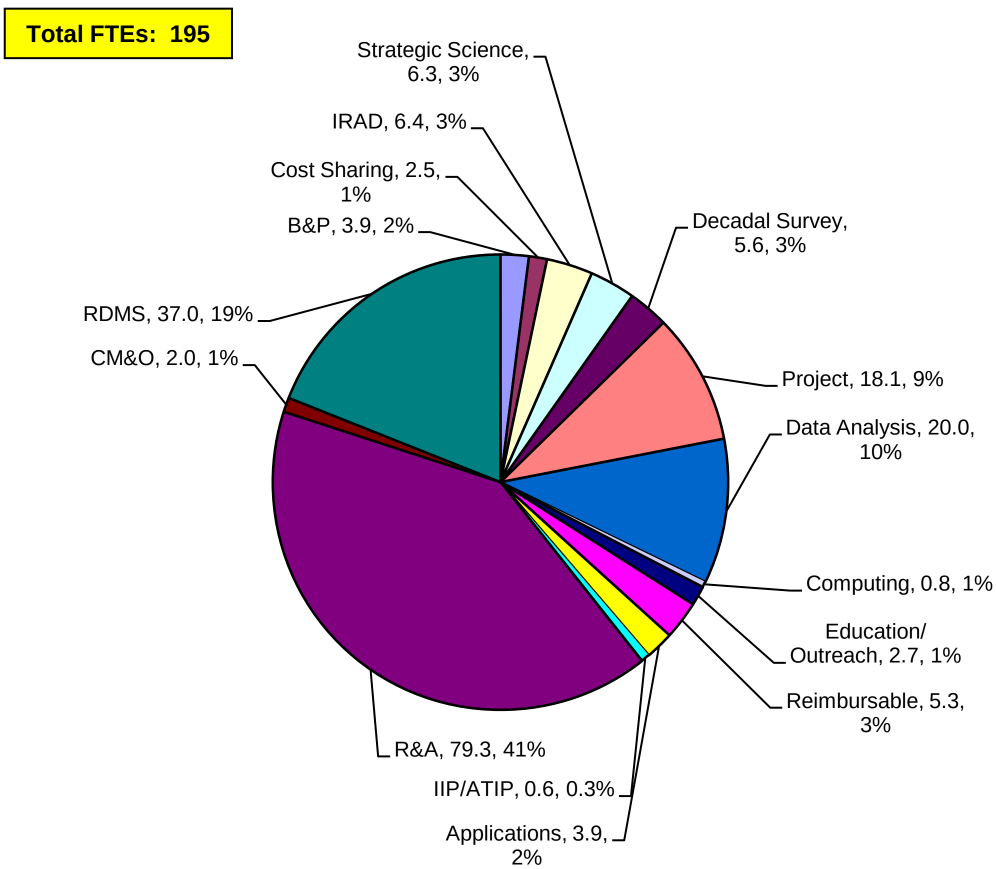


Figure 4. Funding Sources for Fiscal Year 2010 ESD Civil Servant Salaries (FTEs)

The elements in this figure have the same meaning as for Figure 3.

The FTEs chart shows that a large percentage, 51%, of the FTEs comes from the R&A and Data Analysis sources. This points to the major role that writing successful research proposals has in the Division. Indeed, the success rate of the Division scientists has been consistently high ranging in the last three years, between 39-44%. The relatively large percentage of R&A funds results in heavy pressure on the Division scientists, as we will further discuss in Chapter 7.

7. Challenges and Opportunities

In addition to the highly welcomed scientific and technological challenges, scientists in the Division face two significant management challenges: the impact of Full Cost Accounting and an aging work force. These are discussed below.

7.1 The Funding Process and Full Cost Accounting

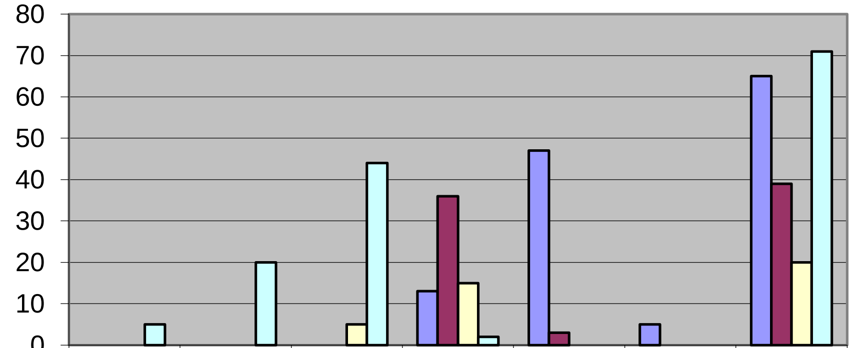
In Full Cost Accounting (FCA), civil servants are responsible for covering their salaries. They have a dual responsibility: on one hand they have to secure funds through competitive proposals to support their research activities (recovery of salaries for themselves, the university scientists they support, contractors, and equipment needs, etc.), and on the other hand they have to actively participate in the process of bringing new instruments and missions to the Center. They play an essential role in defining new scientific questions, in identifying instruments for new measurements and attendant space missions. The pressure on the scientists brought about by FCA is unique.

As shown in Figure 3, about 54% of our research activities are supported by competitive proposals to ROSES or to GSFC internal programs. The majority of this percentage, 51%, comes from ROSES. The civil servant PIs on these proposals have the responsibility for their successes as measured by refereed publications or by producing working instruments. This is an important activity in implementing the NASA agenda directly, as well as indirectly by supporting the outside community. Civil servant scientists need to strike a delicate balance between the time they have committed in the ROSES proposals and the time they need to spend on bringing new work to the Center.

There is no doubt that civil servant scientists spend an increasing amount of time writing proposals at the expense of research and that this has created some morale problems. Possible solutions would be for HQ to increase the strategic FTEs made available to the Division, or to consider base funding at some level for some of the activities in the Division.

7.2 Retention of Skills and New Hires

The ESD faces significant problems relating to its aging civil servant workforce. This is the result of the low number of hires for more than a decade and the reduction in civil servant workforce in the 1990s. The mean age of an ESD civil servant employee is 54 years and the number of retirements in the next 10 years will significantly deplete the core ESD civil servant staff, particularly in the leadership ranks. Figure 5 shows that more than half of the ESD workforce can retire within the next five years. The figure also shows that only about one tenth of our workforce is between ages 30-40. Appendix C outlines a subset of our hiring needs in the near future. This list is in the process of being prioritized.



Age	20-30	30-40	40-50	50-60	60-70	70-80	Totals
Retirement Eligible w/in 1 year	0	0	0	13	47	5	65
Retirement Eligible w/in 5 yrs.	0	0	0	36	3	0	39
Retirement Eligible w/in 10 yrs.	0	0	5	15	0	0	20
Retirement Eligible in 11+ yrs.	5	20	44	2	0	0	71

Figure 5. Demographics for the Division's workforce. It is clear that more than half the work force is eligible for retirement within the next five years, and that there are few young scientists being hired to replace the senior scientists.

It may take 10 to 15 years for a newly minted Ph.D. to develop the scientific credentials and management skills to lead a major scientific mission. Thus it is crucial that we continue to replace core positions in ESD as retirements occur.

The Division has been able to hire 22 new civil servants scientists during the last year and a half. This hiring has allowed us to bring on-board first rate scientists in some of our focus areas.

Our needs persist because of having been unable to hire for several years which resulted in the number of civil servant scientists decreasing from 155 in FY06 to 141 in FY08. Furthermore, the population is aging. The demography is depicted in Figure 5.

We have continued to update our hiring plan following the basic criteria:

- Quality of the candidate.
- Gaps in the expertise existing in a focus area of research.
- Relevance to existing or possible space missions, in particular in relation to acquiring and implementing the NASA missions recommended by the NRC Decadal Survey and in winning Venture Class missions.
- Relevance to the research activities sponsored by NASA HQ and to our ability to play an important role in the science of weather and climate.
- Relevance to the application activities sponsored by NASA HQ in applying scientific results for the benefit of society.
- Role of the candidate towards the goal of achieving a diversified workforce.

The requirements are specified for each research area in Chapter 8. A subset of our hiring needs is shown in Appendix C.

The projected loss of staff in the next few years should allow us the opportunity to hire young people to meet the challenges of the future.

7.3 Some Measures of Performance

Determining the appropriate matrix to assess the performance of a Government laboratory like the ESD is not a simple matter. It is in general difficult to assess the short and long term impact of research. In our case, we can ask several questions:

- How good is our publication record?
- How successful have we been in winning research proposals?
- How good have we been in advocating for new missions for NASA and specifically for Goddard?
- How well have we performed in support of projects?
- How well have we enabled the research community?
- How well have we supported the education of the general public and of the university community in particular?
- How well have we served the activities of our professional societies?

We provide here some quantitative data with the Appendices showing more details.

Research Activities:
- The winning rate for ROSES proposals has varied from 39 to 44% during the last 4 years.
- 380 refereed publications in calendar year 2009; 431 refereed publications in calendar year 2008; 403 refereed publications in calendar year 2007.
- Field campaigns in FY09:
    - 4 scientists were PI's in field campaigns.
    - 2 scientists were Co-PI's in field campaigns.
    - 3 were Co-I's in field campaigns.

Project Support:
- 34 scientists are project scientists or deputy project scientists for missions in operation or in development.

Interactions with the Academic Community:
- 7 active Joint Centers.
- Summer programs for undergraduate and graduate students.
- 20 graduate students at the Joint Centers supported in their graduate studies since 2002.
- 25 scientists were thesis advisors in the academic year 2009.
- 8 courses taught in the academic year 2009.

Service to Professional Societies:
- 24 scientists are fellows of professional societies.
- 12 scientists are members of committees of professional societies.

Awards:
- 19 scientists have received Goddard or NASA awards in calendar year 2009.
- 6 scientists have received national and international awards in calendar year 2009.

7.4 The Opportunity to Apply Terrestrial Knowledge to Other Planets

The new NASA Exploration Initiative places a renewed emphasis on understanding conditions on other planets in order to understand the conditions conducive to the emergence of life and to prepare for an eventual enhanced role of humans in space exploration. ESD promotes the perspective of Earth as a planet through its satellite missions and global modeling activities. The extensive expertise of ESD scientists in these areas, as well as the roots that some ESD scientists have in planetary science, should be leveraged to bring that knowledge to bear more fully in the study of other planets.

Global assimilation techniques refined to optimize the impact of terrestrial satellite data might profitably be applied to development of global analyses of atmospheric conditions from future unmanned Mars orbiters. Global climate models used by ESD to predict anthropogenic climate change might serve as the basis for state-of-the-art general circulation models of other planetary atmospheres. Similarly, ESD expertise in the development and implementation of active remote sensing instruments has many potential applications in planetary research.

Part II

Our Scientific Foci and Strategic Plan

8. Science/Research Areas

In this chapter, we outline the actual activities within the research and technical groups in the Division and identify the proposed activities for the next five years. This part of the document is organized by scientific research area and links to the activities outlined in Chapter 5.1, Table 1.

8.1 Atmospheric Composition

Atmospheric composition research within the Division includes both the gas-phase and aerosol composition of the atmosphere. Both are an essential component of the Earth system and perturb its energy balance. The research in this area involves extensive measurements from space to assess the current composition and to validate the parameterized processes that are used in chemical and climate prediction models. The Division's scientists are involved in instrument and mission development, the ground-based AERONET, ground and aircraft validation campaigns, data analysis and data sets development and distribution.

8.1.1 Atmospheric Chemistry

The area of chemical research dates back to the first satellite ozone missions and the Division has had a strong satellite instrument, aircraft instrument, and modeling presence in the community. The major goal of the atmospheric chemistry research at Goddard is to understand both the composition of the Earth's atmosphere and its changes in response to human-produced compounds, especially in regard to recovery of the ozone layer. A new strategic goal is to understand long-term changes in the chemistry of the troposphere and the importance of long-range transport and the relationship of both to climate change. To attack these goals we use a combination of observations and modeling activities.

The atmospheric composition group at Goddard addresses the following basic scientific questions:

Scientific Questions

- How do anthropogenic activities impact atmospheric pollution at regional and global scales?
- What is the impact of long-range transport of pollutants on local air quality?
- How will climate change impact local air quality and how will changes in atmospheric composition influence climate change?
- How will the stratospheric cooling associated with climate change impact the spatial extent and recovery of the ozone layer and the Antarctic ozone hole?
- Is stratospheric ozone recovering in a manner expected from theoretical predictions?
- How well can we predict atmospheric chemical impacts on ozone and climate?

and has a strong heritage in analyzing satellite data:

Heritage

- Major contribution to the understanding and documentation of the ozone hole.
- Major contributions to the understanding of stratospheric chemistry and dynamics.
- Increasing role and contributions in tropospheric chemistry due to our leadership function in Aura.
- Major role in missions such as TOMS series, UARS, SBUV series, and Aura.
- Production of important long-term ozone data set.
- Two- and three-dimensional modeling for understanding of ozone, chemical transport, and chemistry/climate coupling.
- Major role in international ozone assessments.

- Continuing responsibility in monitoring and studying the stratospheric behavior as mandated by Congress.

The activities of the Division have direct and strong relevance to NASA HQ priorities and to several of the missions recommended in the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Central to at least two of the six NASA Interdisciplinary Science Focus Areas: Atmospheric Composition and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
    - GEOCAPE (Geostationary Coastal and Air Pollution Events) [timeframe: 2013-2016]
    - GACM (Global Atmospheric Composition Mission) [timeframe: 2016-2020]

To be able to maintain the present commitments, to increase our strength in tropospheric chemistry, and to participate in the design of the missions suggested by the NRC Decadal Survey, the Division proposes the hiring of three scientists.

Planning for New Staff to Meet Future Needs:

- Remote Sensing scientist
- Modeling/satellite data analysis scientist
- Senior scientist in the area of atmospheric composition and dynamics

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

8.1.1.1 Observations of Chemical Constituents

Atmospheric chemistry encompasses radiative and dynamical processes associated with tropospheric-stratospheric exchange, ozone recovery and its relationship to climate change, transport of various chemical species in the troposphere and stratosphere, and heterogeneous chemistry - including aerosols. The main efforts of ESD scientists in atmospheric composition over the last 30 years have concentrated on stratospheric ozone. We produced the first daily observations of total column ozone that give near complete global coverage beginning in late 1978 using the Nimbus 7 TOMS instrument. A major achievement of TOMS was the first mapping of the Antarctic ozone hole. Data from TOMS have such high long-term precision, better than 1% per decade; they have become important data for assessing global ozone trends. Data from the OMI instrument on Aura are now being used to continue this high quality ozone time series. The total ozone data were initially derived using a simple algorithm, but as a by-product of algorithm research to increase the accuracy of the ozone time series, new data products such as SO_2, column aerosols, and ultraviolet-B (UV-B) levels have been developed. In addition to TOMS, a number of other instruments have been developed and flown to assess ozone profile information. These other instruments include SBUV, the Shuttle Solar Backscatter Ultraviolet (SSBUV), and the combined Shuttle Ozone Limb Scattering Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE). We are also involved in developing algorithms for the Ozone Mapping and Profiler Suite (OMPS) which will be flown on NPP and NPOESS.

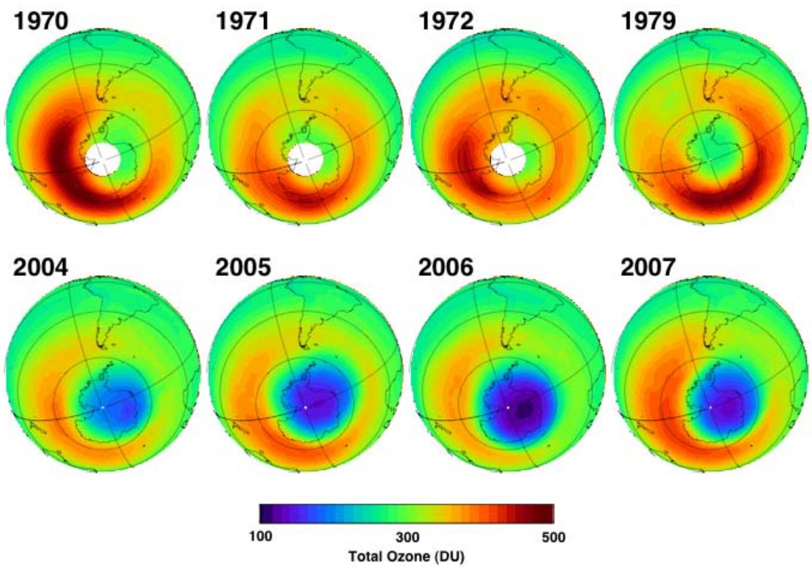


Figure 6. October Antarctic Column Ozone

With the launch of EOS Aura, a significant portion of the research staff is analyzing and validating Aura data. This includes Division led validation missions, research and the archiving of data products. The current research focus is on analyzing data from OMI. OMI is a Dutch-Finnish built instrument that has been flying on NASA's EOS Aura satellite since July 2004. OMI is an advanced hyperspectral instrument that operates in the UV and blue wavelengths. Besides extending and improving the SBUV and TOMS records, several atmospheric species related to air quality are being produced from OMI. These include tropospheric O_3, NO_2, SO_2, HCHO, CHOCHO, and BrO. This effort will continue for at least another decade with OMPS which will fly on NPP and NPOESS satellites, and the Global Ozone Monitoring Experiment (GOME) series of instruments on the European MetOp satellites. These instruments also provide information about light penetration inside clouds. The launch of CloudSat into the A-train with Aura has demonstrated that the cloud pressures provided by UV/Vis measurements (referred to as optical centroid cloud pressures) are distinct from the physical cloud top and more appropriate for use in UV/Vis trace-gas retrievals. In the future, TOMS ozone data will be reprocessed with a cloud climatology based on OMI data. ESD scientists are also involved in satellite constituent retrievals from thermal infrared instruments such as the Aqua Atmospheric Infrared Sounder (AIRS). For example, ESD scientists provided near-real-time retrievals of carbon monoxide (CO) from AIRS in support of multiple field campaign missions. CO data are also used to validate long-range transport in ESD models.

SMD at NASA HQ has developed the “Measurement Team” concept, putting the responsibility for scientific satellite data sets as close to the users of that data set as possible. ESD staff, in particular the ozone group, have pioneered this concept, taking responsibility for retrieval algorithms, instrument calibration and working with data users toward the goal of creating the highest quality data sets, using satellite data from NASA and European research instruments, as well as NOAA operational instruments. ESD scientists continue to improve the quality of this data record by incorporating advances in forward and inverse modeling and calibration methods. As a by-product of this activity, several long-term data sets, some of them spanning almost 40 years, have been produced from the TOMS-series of instruments that include volcanic sulfur dioxide, UV-B, and UV-absorbing aerosols produced by biomass burning and desert dust. ESD staff will continue this model of scientific data set production creating a science quality ozone data set from Nimbus 7 TOMS (1978), through EOS OMI (2004), onto OMPS on NPP (2011), and onto the NPOESS era (2014) as indicated in Chapter 8.5.1.

During the next four years, the reflectivity data from all of the TOMS, SBUV-2, OMI, and SeaWiFS will be combined to create a climate data record stretching back to 1979. This data record will be extended using GOME and the future NPP and NPOESS satellite instruments. Based on the first year's work, we will be able to determine whether there has been any long-term change in cloud cover over the land and oceans in response to global warming. Preliminary results indicate that there has been a small increase in cloud cover that is consistent with the independently developed data indicating global dimming (less light reaching the Earth's surface). In addition, we have found local areas of decreasing cloud cover over parts of Europe and the U.S. leading to increased amounts of UV exposure.

In addition, analysis of the data from the Upper Atmosphere Research Satellite (UARS) provided a better understanding of the trends and variability of stratospheric ozone and has helped guide government policy for the regulation of ozone depleting substances. The Division continues to work with other data sets including occultation instruments [Polar Ozone and Aerosol Measurement (POAM), Stratospheric Aerosol and Gas Experiment (SAGE) III, Aerosol Characterization Experiments (ACE), and the Halogen Occultation Experiment (HALOE)] as well as data from GOME and the ENVIronment SATellite (ENVISAT).

Over the next five years, ESD ground and aircraft observations will be focused on continued support for satellite measurements including those from Aura and Aqua; the Network for the Detection of Atmospheric Chemical Change (NDACC) ground-based network, and the Southern Hemisphere Additional Ozonesondes (SHADOZ) balloon network. In particular, the NDACC will be supported by the Stratospheric Ozone Lidar Trailer Experiment (STROZ-LITE) measuring ozone aerosol, temperature, and water vapor profiles; and by the Aerosol and Temperature Lidar (ATL) measuring aerosol scattering, extinction, depolarization, stratospheric and tropospheric temperature, and water vapor. In the near future, a tropospheric ozone lidar capability will be added to the ATL to provide observations for OMI comparisons. All data from these lidar instruments are also used in support of Aura measurements. The Global Hawk Pacific Experiment (GloPac) will be the first science mission flown on the Global Hawk UAS. Work continues on the development of a ground-based CO_2 lidar to make routine, highly accurate profile measurements for monitoring and field mission support. ESD scientists are collaborating with scientists from Langley Research Center to develop downward looking, ozone lidar instruments for the Global Hawk and ER-2 aircraft for future missions.

During the past two years, new accurate ground-based low cost instruments (Pandora and Cleo costing less than \$12,000) have been developed to measure trace gas amounts and aerosol properties to validate satellite measurements (OMI, GOME, and future NPP and NPPOES instruments), explore the details of tropospheric chemistry, and to determine air quality at multiple sites. Extending the 3 Pandora spectrometers currently operating, a network of these (20 instruments) will be deployed during the next two years at various sites throughout the world. The Pandora systems are capable of measuring O_3, SO_2, HCHO, NO_2, and H_2O column amounts with good accuracy (1%) and very high precision (0.1%). Uniquely, the Pandora system can determine ozone profiles from the ground to 50 km every 15 minutes throughout the day, which is especially important for satellite validation and air quality measurements. In addition, the Pandora spectrometers have the capability of making aerosol optical property and particle size measurements as a function of wavelength from 300 to 520 nm in 0.5 nm steps. The importance of the new aerosol measurement has been established by recent shadowband data, which show that the absorption properties of aerosols in the UV are different than those based on extrapolations of AERosol Robotic NETwork (AERONET) data. The absorption properties in the UV permit the determination of the type of aerosol and are required for improved model estimates of tropospheric chemistry. The Cleo spectrometer systems are an advanced version of the shadowband instruments, but are capable of measuring aerosol properties from 300 to 800 nm in 1 nm steps and O_3, SO_2, and H_2O column amounts. Unlike the original shadowband, the Cleo version can be field calibrated without an expensive laboratory setup. This makes them ideal for a widely distributed network of low maintenance instruments.

The Division has also hired an experimental scientist to spearhead the development of a capability for in-situ measurements aboard aircraft and balloons. These measurements, based on the Laser Induced Fluorescence technique, are expected to prove useful in developing new capabilities for validation of satellite data of species such as formaldehyde.

ESD will continue to work with NASA HQ to develop systems to: (1) predict global ozone change in the stratosphere and troposphere, (2) determine the impact of climate change and intercontinental transport of pollution on local air quality, and (3) establish aerosol distributions, aerosol effects on atmospheric constituents and clouds, and the combined effects on climate. In particular, ESD scientists are collaborating with NASA HQ in feasibility studies of the satellite missions detailed in the NRC Decadal Survey. Development of future satellite observations depends on the lessons learned from ongoing efforts with currently flying satellite instrumentation: Aura's OMI instrument, TOMS, SBUV-2, and the European instruments GOME and SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY). Studies are currently under way to refine scientific goals and measurement requirements for the GEOCAPE mission. In addition, the Airborne Compact Atmospheric Mapper (ACAM), a UV/Vis high resolution instrument developed under an Instrument Incubator Project (IIP) project, has flown aboard the WB-57 in the Tropical Composition, Cloud, and Climate Coupling Experiment (TC^4) and Newly-Operating and Validated Instruments Comparison Experiments (NOVICE) campaigns, and will participate in the Global Hawk Pacific Mission (GloPac). A concept for a Venture-type mission for stratospheric measurements, the Chemical and Aerosol satellite Sounding System (CASS), is also under study. All these activities may be hampered by the retirement of experimental scientists in UV detection and calibration, and new hires are legitimately needed to continue this activity and maintain our world leadership.

Code 613.3 scientists are participating in the support, execution, and development of aircraft field missions. ESD scientists provided on-site support in chemical forecast of CO and aerosols for the Arctic Research of the Composition of the Troposphere from Aircraft and Satellite (ARCTAS), during both the spring 2008 and summer 2008 deployments. Support of ARCTAS will continue through post-mission analysis of aircraft and satellite data. GloPac will be the first science mission flown on the Global Hawk UAS. GloPac will fly a mix of in situ and remote sensing instruments for supporting Aura validation, and exploring issues related to stratospheric ozone depletion, aerosol transport, and global pollution. Code 613.3 is contributing to GloPac with project science leadership, flight planning, and the ACAM UV-Vis instrument. The Pacific Atmospheric Composition, Cloud, and Climate Experiment (PAC3E) is a multi-Agency, NASA multi- program, field mission to investigate the structure, properties and processes in the tropical tropopause transition layer (TTL), and the chemistry of the lower troposphere over the tropical Western Pacific. The PAC3E mission is currently in the development stage, but is tentatively planned for August and September of 2011.

In addition to GloPac and PAC3E, Code 613.3 scientists are beginning work on a number of missions that will be proposed under the Venture Class. The first Venture Class NASA Research Announcement (NRA) was released in 2010, with funding for 2011. Proposals were submitted to work on the Hurricane and Severe Storm Sentinel Mission (HS3) in collaboration with NASA/Ames, Surface Conditions from Column and Vertically-Resolved Observations Relevant to Air Quality in collaboration with NASA/Langley, and Global Mission to the Troposphere, in collaboration with NASA/Ames.

8.1.1.2 Chemical Modeling

We construct computer-based models of the atmosphere by bringing together our knowledge of atmospheric processes to better understand how the system operates as a whole. Chemical models are focused on understanding the processes that determine the chemical composition of the atmosphere. ESD chemical models are used in five areas: (1) modeling of the past, and of past events, to determine what factors influenced the observed time-series of data; (2) sensitivity studies in which input parameters to a model are varied to understand how certain processes affect the model and the atmosphere; (3) field campaign and satellite support to provide a complete picture of atmospheric composition; (4) incorporation of all of the above information into projections of future changes in composition on the decadal to century time scale that will help inform the international assessment process; and (5) support for the development of new satellite instruments and sampling strategies.

The development of our chemical modeling capability is one part of the overall ESD goal to develop comprehensive Earth system models. There are a number of efforts in chemical modeling that contribute to this goal, including: (1) the Goddard Earth Observing System Chemistry Climate Model (GEOS CCM); (2) the Global Modeling Initiative (GMI); (3) the stratospheric Chemical Transport Model (CTM) in both two and three dimensions; (4) the Goddard Global Ozone Chemistry Aerosol Radiation and Transport (GOCART, described in Chapter 8.1.2) model; (5) aerosol micro-physics and composition modeling (also described in Chapter 8.1.2); and (6) mesoscale modeling. These efforts are used in different applications but have a strong common element, the use of constituent observations to evaluate and improve the representation of processes in the models to provide better potential for reliable future predictions. These efforts are closely coupled to the development of the underlying general circulation model(s) and are part of the development process for including improved representations of processes in the model and pushing it forward toward the goal of a comprehensive Earth system model.

A CTM requires meteorological fields for the transport of chemical species. One source is the Atmospheric General Circulation Model (AGCM), developed within the Division and also used for the Goddard Earth Observing System (GEOS)-4 data assimilation project. The present AGCM relies on ozone climatology, and there is no feedback between chemistry and the other components. In a nascent version of this ACGM, constituents are transported online. Chemical changes to ozone and other constituents are calculated, and computed fields of ozone and other radiatively active constituents are input to the radiation module. The GMAO has developed a new, computationally efficient model (GEOS-5 AGCM) with updated physics. This model also serves as the core of the new atmospheric data assimilation system and of the coupled climate prediction system. Meteorological fields from this model are also used for transport by GMI, the CTM, and the GOCART model. Hence, one of the foci for improvements to the GEOS-5 model is to provide better meteorological fields for GMI and GOCART in addition to the assimilation, weather, and climate prediction applications. Over the next five years, the chemical modeling group and the assimilation group will be jointly developing chemical forecasting models as discussed in Chapter 8.4.2.3, Prediction of Constituents—Chemical Weather Prediction. More details on the chemical models are given below.

Chemical Transport Model and the Global Modeling Initiative

GMI is a broad community effort funded by NASA HQ that is managed by ESD. The goal of GMI is to develop and maintain a state-of-the-art modular 3D CTM that can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry. The GMI CTM includes both tropospheric and stratospheric chemistry and is being used to fully realize the benefits of the trace gas measurements in the lower stratosphere and troposphere that are being made by instruments on Aura. Such applications are a prerequisite to interpretation of simulations using the fully coupled version of GEOS-5 (see below). In addition, the CTM also includes aerosol modules such as GOCART as well as microphysical modules. The GMI chemistry has been incorporated into the GEOS-5 framework to allow for future coupled chemistry-climate simulations encompassing both the troposphere and the stratosphere. Current efforts are targeting the full incorporation of the GMI model into the GEOS-5 framework, allowing for a CTM capability within the same computational framework.

A particular focus of GMI is to reduce the uncertainty in assessment by making it possible to determine the sensitivity of results to various model components. GMI will be mainly used for producing hindcasts, forecasts, and for sensitivity studies.

Chemistry-Climate Model (CCM)

The chemistry-climate model is now in its third year of development. This effort is a collaboration between the Atmospheric Chemistry and Dynamics Branch (ACDB, Code 613.3) and the GMAO. It combines the CTMs developed in ACDB with the GEOS General Circulation Models (GCMs) developed in the GMAO. The first version of this effort coupled the 3D stratospheric CTM developed over the past two decades in ACDB with the GEOS-4 atmospheric GCM. The goals of this effort were to better understand how the recovery of the ozone layer would take place as the underlying climate changed and how the ozone depletion and recovery might affect the climate. This version of the model was used as part of the 2006 WMO/UNEP Ozone Assessment and has been part of an international inter-comparison of chemistry-climate models. An updated version of the model now couples the stratospheric chemistry to the GEOS-5 atmospheric GCM. This version will be used for the upcoming 2010 WMO/UNEP Ozone Assessment. A third version that uses the combined stratosphere-troposphere chemistry (Combo) developed by GMI is now being tested and evaluated. This version will have seamless prediction of ozone in both the troposphere and stratosphere for better evaluation of its impact on climate change. The future for the chemistry-climate modeling effort includes both improvement in the underlying model through extensive data comparisons, and extension of the coupling in the model to include the aerosol-chemistry processes and the ocean-atmosphere GCM.

Mesoscale Chemical Modeling

Global scale models are currently too computationally costly to reasonably resolve urban scale (<10 km) chemical composition. For the urban scale chemical composition, mesoscale models have been developed that include large-scale boundary inputs from global scale models. The mesoscale modeling effort is currently being developed to support satellite and field missions, sensitivity studies, and satellite mission development. We are currently using and refining the Weather Research and Forecasting (WRF) regional model to include aerosols and chemistry in a way that is (1) flexible in terms of spatial resolution (from sub-100 km to a few km) and geographic location and is ready to run in forecast, analysis, and testing modes, and (2) can be nested within the global model to study the regional-global interactions. This model is also a component of the definition studies for future missions.

Future Chemical Research

In the near term, we are focusing on the questions of how ozone will recover in a changing climate and how that recovery will affect the climate. With the version of the CCM including the combined stratosphere-troposphere chemistry we will begin to ask questions about how stratospheric ozone recovery affects tropospheric chemistry, and possibly air pollution. Simulations with our first version of the CCM have shown how stratospheric ozone and circulation are expected to respond to climate change driven by greenhouse gases (GHG). Simulations from 1950 to 2100 have shown that, as ozone-depleting substances (ODS) are removed from the stratosphere, ozone does not recover to the same distribution as existed before ODS were introduced. This is because of stratospheric cooling due to GHG and a possible change in the circulation of the stratosphere. We will do several simulations with the combined stratosphere-troposphere chemistry to separately evaluate the response of tropospheric chemistry to changes in both ODS and GHG. Longer-term plans for this version of the model will include biogeochemical processes at the surface that can respond to changes in climate, thus providing variable inputs of chemicals to the atmospheric system. This advanced version of the model will be used for assessing the interaction of GHG and ODS with natural biological processes.

One of the results from our present studies is a better understanding of the role of sea-surface temperatures (SSTs) in the circulation and composition of the stratosphere. The atmospheric GCM uses SSTs specified from either observations or from simulations by coupled ocean-atmosphere models. The sensitivity of many of our results to SST assumptions highlights the importance of moving the CCM toward the use of a coupled ocean-atmosphere GCM. The development of such a model in GMAO provides us with an opportunity to further extend the coupled CCM in this direction.

Another important direction for extending the coupling of processes is in the area of aerosol-chemistry interactions. The GOCART model (described in Chapter 8.1.2) has been implemented within the GEOS-5 framework and independently within GMI. The GMI implementation focuses on the issues of chemistry-aerosol interactions. These two implementations will be brought together within the GEOS-5 CCM framework to fully couple aerosols to both the chemistry and the circulation of the atmosphere. Part of this task involves the important connections with natural sources of atmospheric chemicals, particularly sulfur compounds and organic compounds. These developments are enabled by the fact that we now have global satellite data from Aura and other satellites for some of the key compounds. Without these data, we could develop the models to include processes, but would have no way to test their reality, thus limiting the advancement of knowledge.

The GMI/GOCART CTM capability is an important part of the testing of the chemical coupling throughout the atmospheric system, especially the relationship of the composition to sources and to the variations with changing climate. The CTM framework, both for GMI and GOCART, make for straightforward interpretation of sensitivity studies. The CCM framework couples many interactions to get a representation of important feedback process, but this coupling can make sensitivity studies hard to interpret.

The mesoscale chemical model will be used in the next few years for studies showing how high-resolution satellite measurements of tropospheric pollution will lead to a better understanding of pollutant transport from local sources to regional and global scales. It will also be used for satellite mission support and data analysis for aircraft and other specific field experiments.

8.1.2 Atmospheric Aerosols

Atmospheric aerosols are an essential component of the Earth climate system, perturbing the Earth's energy balance and influencing the hydrological cycle, precipitation, and weather. Aerosols both reflect and absorb solar radiation, which may counteract global warming from greenhouse gases, but can also redistribute energy within the atmospheric column, and in some cases amplify the warming regionally. Aerosols are key to understanding climate change. Aerosols activities at GSFC are well recognized nationally and internationally. They are central to at least two of the six NASA Interdisciplinary Science Focus Areas: Atmospheric Composition and Climate Variability and Change and they are directly related to the following missions recommended in the NRC Decadal Survey: GEOCAPE and ACE. The aerosols activities address the following:

Scientific Questions

- How do aerosols affect regional weather and climate?
- How do aerosols affect the Earth's heat balance?
- How do aerosols affect cloud and precipitation?
- How do aerosols affect ecosystems?
- How do aerosols affect health?

The ESD has a strong record of activities in aerosols:

Heritage

- Aerosols research at GSFC dates back to the late 1970s beginning with NOAA's Advanced Very High Resolution Radiometer (AVHRR) and the Landsat instruments.
- The Goddard Center of Excellence in Aerosol Research (AeroCenter) was established in 2000 and has had hundreds of visitors.
- The AERONET and MPLNET were established in support of the EOS program.
- Radiometers, lidars, and comprehensive observational systems have been designed here to measure aerosols, water vapor, and surface reflectance. Surface-sensing

Measurements for Atmospheric Radiative Transfer (SMART) and Chemical, Optical, and Microphysical Measurements of In-situ Troposphere (COMMIT) are two such examples.
- The Glory mission was conceived at GSFC and is managed here.
- Major use of data is made from TOMS, the Multi-angle Imaging SpectroRadiometer (MISR), the Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua and Terra, OMI on Aura, ICESat, and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO).
- Modeling and data assimilation efforts have been conducted to study the transport of aerosols and their effect on weather and climate.
- GSFC has played a key leadership role in major field campaigns.
- Data sets produced by MODIS for aerosols optical thickness and cloud properties have been created and made available to the scientific community.

The activities in the aerosol area have clearly been supportive of the HQ focus area and are directly related to some of the missions recommended by the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey
- Central to at least two of the six NASA Interdisciplinary Science Focus Areas: Atmospheric Composition and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - GEOCAPE (Geostationary Coastal and Air Pollution Events) [timeframe: 2013-2016]
  - ACE (Aerosol and cloud profiles for climate and water cycle) [timeframe: 2013-2016]

Planning for New Staff to Meet Future Needs:

- Instrument physicist
- Aerosols and clouds remote sensing expert

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

The goal of aerosol research at Goddard is to improve our prediction of the impact of aerosols on climate, and to enhance our understanding of the chemical, physical, radiative, and meteorological processes of aerosols. Because aerosols, clouds, and climate are inherently linked within the hydrological cycle, much aerosol research in the future will coincide with research of hydrospheric processes described in Chapter 8.2.4. Although there have been several new civil servant hires in this focus area, we are still missing some key expertise to address the interaction of aerosols, rainfall, clouds, and large-scale circulation. These hiring needs are discussed in Appendix C.

Cloud, aerosol and radiation area, research priorities have focused on the retrieval of optical and radiative properties of clouds and aerosols. These data sets are listed in Chapter 8.5.1. Data from the AVHRR, Terra (MISR and MODIS), Aqua (MODIS), TOMS, and SeaWiFS were used in this research. With the launch of EOS Aura, the OMI instrument is also providing aerosol observations. The “A-Train” – a series of satellites [Aqua, CALIPSO, CloudSat, Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL) and Aura] will be making near simultaneous observations because they are clustered together along the same orbit path. This enables us to develop joint retrieval algorithms using individual strengths from individual sensors, and to focus on cloud-aerosol-climate interaction. Key to remote sensing of aerosol processes will be the measurement of aerosol height by CALIPSO’s lidar and the polarization from the POLarization and Directionality of the Earth’s Reflectance (POLDER) (on PARASOL). Over the next five years, the aerosol group will be analyzing the aerosol data from the A-Train. Much more precise aerosol retrievals will be obtained from polarization measurements from the Glory Aerosol Polarimetry Sensor - a passive instrument with unparalleled capability to diagnose aerosol chemical composition as well as retrieve detailed aerosol and cloud particle size distribution and shape information. Measurements of the key parameters will continue through NPP and NPOESS, and we look forward to the implementation of a specific measurement team for clouds and aerosols in the NPP era.

A strong modeling component will continue to be part of the satellite program. The GOCART aerosol transport model has proven to be very successful in providing information on sources and sinks and transport of various aerosol and chemical species. With the coupling of GOCART with the GEOS-5 AGCM, we are beginning to expand the studies of chemical transport modeling and assimilation, including the feedbacks that impact not only climate but also weather prediction.

Within the next five years, the aerosol research focus will be:

Description of the Global Aerosol Distribution and Optical Properties

We are moving toward a synthesis of sensors and techniques to improve remote sensing of the aerosol properties. Using the new satellite data from MODIS, MISR, OMI, CALIPSO, PARASOL and (later) Glory APS along with the AERONET and new techniques that include 3D radiative transfer, we intend to create a long-term climate data record and a new aerosol assimilation system. The satellite data can be combined with comprehensive ground-based remote sensing and in-situ measurements and used to constrain aerosol models. The models assimilate the data, generating cohesive data sets, and also interpolate into cloudy regions and regions where the satellite cannot detect the aerosol with sufficient accuracy. We will use the hybrid of observations and model simulations to determine sources and sinks of aerosol, and of processes not well understood. This global distribution of aerosol can then be used to assess the effects on climate, human health, and natural hazards.

Determining the Effect of Aerosols on the Direct Forcing of Climate

Our current assessment of aerosol radiative forcing is hindered by our incomplete knowledge of aerosol optical properties, especially absorption, and our current inability to determine the aerosol distribution near, under, and above clouds. New sensors such as OMI for absorption, CALIPSO for separating aerosol and clouds, and Aerosol Polarimeter Sensor (APS) for detailed aerosol characterization, along with the assimilation system will help alleviate our current difficulties. We will then be able to better compute the direct radiative forcing of the aerosol in the presence of clouds and over varying surface properties.

Effect of Aerosols on Clouds, Precipitation, and Indirect Forcing

The direct radiative forcing by aerosol constitutes only part of the aerosol effect on climate. Aerosols also have an effect on clouds and precipitation. These effects depend on the aerosol size- and composition-dependent hygroscopicity, on the dynamical properties of the cloud field, and on the perturbations to atmospheric stability caused by vertical distributions of absorbing aerosol. Simultaneous precise measurements of aerosol properties and the cloud field from satellites, coupled with cloud resolving models such as the Goddard Cumulus Ensemble (GCE), should provide the basic relationships between aerosols, microphysical properties, reflectivity of clouds, and rate of precipitation. In order to establish a definitive cause and effect relationship between the aerosol and the cloud / precipitation field, the models need to assess the likelihood of alternative causes for the apparent correlation between aerosol and clouds. To help address these issues, we need to employ global models that represent the circulations of the atmosphere and plan to improve the model physics by incorporating aerosol microphysics within the convective parameterization scheme of GEOS. Then, carefully controlled model experiments and comparisons with observations will be needed to sort out the complex relationships.

Assessing Past Climate Forcing by Aerosols

We study today's aerosol-laden atmosphere, and using reanalyzed historical data sets we can describe past aerosol distribution and forcing using the 25 year record of AVHRR and TOMS (see Chapter 8.5.1). Because these sensors are now flying simultaneously with the more modern suite of instruments, the data sets can be compared with MODIS and AERONET to improve the measurements. In essence we can "calibrate" the old data with the new, and then assess the past with a "calibrated" time series. This time series will itself become the testbed for predictive models that will use the lengthy observational record for evaluating the models' ability to simulate interannual variability and interdecadal trends. The Global Aerosol Climatology Project will provide a satellite-based data set spanning these multiple sensors (see Chapter 8.5.1). The tuned models then travel even further back in time to give us a glance at pre-satellite and pre-industrial aerosol distribution, with limitations. At present, a coupled aerosol-GEOS-5 climate model (aerosol direct effect only) is being developed and tested. In a few years, a fully interactive aerosol-GEOS-5, including direct and indirect effects will be available. This model can be used to simulate past climate, and provides future climate projections under various greenhouse gases forcing scenarios, with realistic aerosol forcing and dynamical responses. The climate data record and model assimilation will continue beyond the Terra and A-train era, as NPP and NPOESS provide a continuing data stream.

Assessing the Effects of Aerosols on Air Quality and Human Health
Satellite observations are currently expanding the capability of air quality forecasting in the United States. As remote sensing techniques improve to better characterize the 3D spatial distribution and properties of the aerosol, we will continue to work with our partners in other federal agencies to improve air quality forecasting techniques. Satellite data coupled with global models will also bring a global perspective and quantification of the long-range transport of air pollutants.

8.2 Hydrospheric Processes

Hydrospheric processes encompass all aspects of the Earth's global water cycle, including the cryosphere, land surface hydrology, physical oceanography, coastal zone processes, atmospheric precipitation and moisture, plus the techniques for observing, modeling, and prediction of these processes. There is significant overlap between the hydrospheric and atmospheric research activities within ESD.

8.2.1 Oceanography

The relatively large mass and heat capacity of the world's oceans make them essential to any discussion of climate change, both in terms of thermal and carbon related issues. The ocean is habitually a hostile environment for acquiring *in situ* measurements, thus detailed knowledge of the ocean's role in climate change and carbon processes is limited. Satellite measurements are the only viable option for obtaining global information about the ocean on the temporal scales necessary to resolve key ocean processes. GSFC's hegemony in satellite-based oceanography is evident from its initiatives and very strong participation in project work, data processing, and NASA science teams.

The GSFC ocean community addresses the following basic inquiries:

Scientific Questions
- How does the ocean circulation and biology contribute and react to changes in the global climate system?
- What is the character and variability of the global ocean biology that is detectable through changes in ocean color?
- What is the ocean's physical and biological response to changes in its near surface vertical density gradient?

and has a strong heritage in using satellite data:

Heritage

- Leadership in the science team for MODIS (oceans), NPP/Visible Infrared Imager Radiometer Suite (VIIRS), and SeaWiFS.
- Responsibility for the data processing for MODIS (color and sea-surface temperature) and SeaWiFS.
- Responsibility for the Global High Resolution Sea Surface Temperature (GHRSST) products.
- Responsibility for calibration and validation for satellite-based ocean color data.
- Responsibility for the development of coupled ocean-land-atmosphere globally integrated models to study the Earth system and to utilize satellite data to improve forecasts at all scales, and in particular, for El Niño/Southern Oscillation forecasts.

The Division will manage the post-launch operational phases, data processing, and ground system for Aquarius. Aquarius is a NASA mission scheduled for launch in spring 2010 to measure global ocean surface salinity.

The Division will continue to support the NPP/VIIRS mission and team.

The activities of the Division have direct and strong relevance to NASA HQ priorities and to several of the missions recommended in the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Directly related to many of the six NASA Interdisciplinary Science Focus Areas. In particular to Carbon Cycle and Ecosystems, Water and Energy Cycle, and Climate Variability and Change.
- Directly related to NASA's upcoming Aquarius mission
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - ICESat II (Ice, Cloud, and Land Elevation Satellite–II) [timeframe: 2010-2013]
  - SWOT (Surface Water Ocean Topography) [timeframe: 2013-2016]
  - ACE (Aerosol-Cloud-Ecosystem) [timeframe: 2013-2016]
  - GEOCAPE (Geostationary Coastal and Air Pollution Events) [timeframe: 2013-2016]

To be able to maintain the present commitments, to support Aquarius and to participate in the design of the missions suggested by the NRC Decadal Survey, the Division proposes the hiring of two scientists.

Planning for New Staff to Meet Future Needs:

- Ocean color scientist to help lead future missions
- Sea-surface temperature/salinity scientist

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

8.2.1.1 Physical Oceanography

The opaqueness of water to electromagnetic radiation creates a condition over much of the open ocean of a relatively thin, warmer upper layer shielding a much thicker, colder, and more saline layer below that is generally insulated from interactions with the atmosphere. As a result of these characteristics, critical scientific questions on the oceans effect on climate involve understanding how large quantities of heat and water are transported in the thin, yet still high capacity, atmospheric-driven upper layer that represents only 3% of the total ocean volume, and how changes in the stratification between the upper and lower layer affects the heat and mass transport in the slower moving but much more massive lower layer. The thin upper layer transports approximately the same amount of heat from equator to pole as the atmosphere, and the thermal inertia of the slow-moving lower layer can affect climate change on temporal scales of several centuries. The lower layer closes the loop for the return flow of an oceanic Hadley circulation, often referred to as the meridional overturning circulation in the ocean.

The ocean's near opacity to electromagnetic radiation limits satellite observations to the very near surface. However, over much of the ocean, the thickness of the thin upper layer is manifest with a signature in the surface height due mainly to the thermal expansion properties of water. Thus, the surface measurement of ocean surface topography is used both to understand changes in the total ocean heat content, and through geostrophic assumptions, to provide an estimate of the currents that transport heat and mass in the upper ocean layers. The Division's physical oceanography research has its roots in ocean surface topography and wind measurements that led to the Ocean TOPography EXperiment (TOPEX)/Poseidon and QuickScat missions, and the realization that measurements of sea surface topography, temperature, and winds were all required to describe the ocean surface variability associated with El Niño/Southern Oscillations (ENSO). The Division continues to support satellite altimeter and ocean vector wind measurements through collaborations with the French on the TOPEX follow-on missions such as JASON-1 and -2, and with the U.S. Navy on the GeoSat Follow-On (GFO) Mission. An important offshoot of this research has been the laser altimetry capabilities resulting in the ICESat and the Mars Orbiter Laser Altimeter (MOLA). The Division's ocean altimetry-circulation-climate research efforts of the past have included the NASA Seasonal to Interannual Prediction Project (NSIPP, now GMAO), that studied relationships between global ocean dynamics and seasonal to interannual climate variability, and also provided the critical modeling tools to extend the satellite surface measurements throughout the entire ocean column enabling study of changes in the longer time scales of the oceans' deeper levels.

The new challenge of utilizing sea-surface salinity data adds a critical state parameter for satellite-based ocean research. Goddard leadership of the Aquarius sea-surface salinity Earth System Science Pathfinder (ESSP)-3 mission includes the project Co-PI, delivery of the mission-critical radiometer, algorithm development, the ground data system, and post-launch project operations. Aquarius data, along with fresh water fluxes and high latitude sea-surface height estimates from ICESat II will improve understanding of the density driven ocean circulations, particularly the longer time scale thermohaline circulations, and the vertical mixing processes that are critical to understanding exchanges of properties between the ocean and atmosphere, and between the lower and upper ocean layers. These broad commitments to monitor changes in the ocean surface in response to climate variability and the effects on the longer time scale ocean circulations are a Divisional major five-year research goal. In addition, Division staff are active in research linked to the uninterrupted sea-surface height time series starting in 1992 from high-accuracy radar altimeters. The planned Surface Water/Ocean Topography insures this time series continues in the future and provides an observational basis for investigating and modeling decadal and climate scale ocean variability such as the Atlantic Meridional Overturning Circulation.

In support of this effort, the physical oceanography science staff is being rejuvenated to address the ocean salinity algorithm, and to support and lead the post-launch Aquarius project. New staff will therefore be added to the Aquarius/physical oceanography effort. These new recruits will address satellite retrievals of ocean salinity, roughness, and other parameters including air-sea interaction. They will coordinate with existing staff in ongoing research including data analysis and modeling of the general ocean circulation; the linkages between altimetry, salinity, SST, vertical mixing, and ocean circulation; and improved understanding of the linkages between sea ice and ocean circulation.

8.2.1.2 Biological Oceanography

NASA biological oceanography research spans the fields of ocean color and its relationship to oceanic primary productivity and the carbon cycle. The research and development activities extend from space missions and mission data delivery, to ocean biology laboratories that investigate phytoplankton growth and optical properties, to in-situ and remote measurement research, and a sophisticated coupled physical-biological-chemical model of the global ocean. These activities seek to clarify, and through modeling and assimilation, predict the role of the single largest reservoir of carbon on the planet by far, the ocean, and how changes in ocean biology affect and are affected by climate change. Scientific studies and an extensive array of ocean biology laboratories focus on the relationship between phytoplankton development and light levels in the sea, on global ocean productivity, on dissolved organic carbon and the ocean carbon cycle, on exchange and mixing processes between the upper and subsurface ocean layers, and on tropical ocean biogeochemistry. These studies are buttressed by shipboard field observations, and by development of optical systems for observing the characteristics of phytoplankton both in the laboratory and at sea.

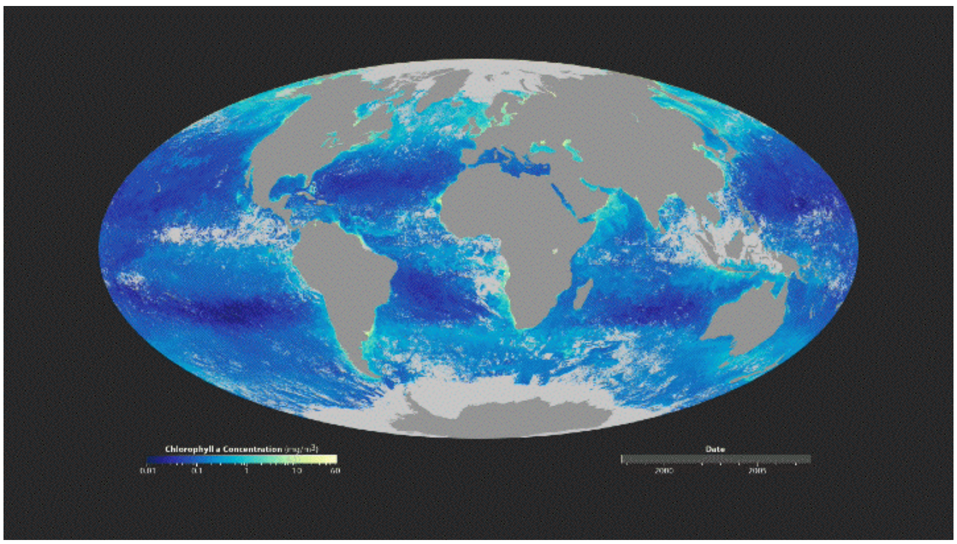


Figure 7. The Carbon Cycle: Phytoplankton [*Sea-viewing Wide Field-of-View Sensor Orbview-2 (1997–2007)*]

The Division has provided quantitative global ocean bio-optical data products from the SeaWiFS Project to the Earth science community over the past eleven years. We currently support MODIS/Aqua ocean color processing and the ocean color activities associated with the NPOESS program. Additionally, we provide community ocean color data product validation, sensor calibration, data merger algorithm evaluation, and satellite data processing. We continue our ongoing climate data record effort to develop and maintain a consistent multi-decadal time series of ocean color data, extending across a multitude of sensors, from the early Coastal Zone Color Scanner (CZCS) data (ca. 1978-1986), through the Ocean Color and Thermal Scanner (OCTS) (a Japanese sensor, 1996-1997), SeaWiFS (1997-present), to the current data stream from MODIS (2000-present). This consistent time series is a critical aspect of assessing climate change – primary productivity issues, and relates closely to our coupled physical-biological modeling and ocean color data assimilation, which addresses the large-scale variations in ocean color data observed from satellite. Since ocean color satellites observe only the near surface of the ocean, assimilation systems are essential to tie the surface observations to variations beneath the surface. This is an essential step in a comprehensive Earth system assimilation system that provides a consistent synthesis of observations across all components of this complex environment.

Our carefully focused ocean biology laboratories provide new insights into ocean color/phytoplankton physiology algorithms and ocean taxonomy. With mission proposals such as Ocean Carbon Ecosystems and Near-Shore (OCEaNS), and the NRC Decadal Survey proposed

ACE and GEOCAPE missions, we are aggressive leaders in the definition and development of the next generation of ocean color research satellites. Our five-year goals include continuing our responsibility for future ocean color algorithms for VIIRS on NPP/NPOESS and subsequent ocean color sensors such as the Ocean Remote Chemical/optical Analyzer (ORCA), and instruments on ACE and GEOCAPE. We will also continue a vigorous modeling program to aid in proposing accuracy requirements and observational strategies for new ocean color missions. In addition, we will use the successful ocean biology processing system to provide an efficient mechanism for mission data processing for the upcoming Aquarius ocean salinity mission.

8.2.2 Polar Climate Change

The Earth's ice cover exhibits an enormous influence on global climate through the regulation of energy and moisture exchanges between the ocean, atmosphere, and land; and through the potential of the great ice sheets to raise sea level dramatically. The importance of the Earth's ice is underscored by the fact that it is one of the most sensitive aspects of the Earth's climate system, in large part because of the positive albedo feedback associated with the melting or removal of ice. The rapid decay of Arctic ice – significantly underestimated by climate models – the potential instability of the Greenland and West Antarctic ice sheets, and the importance and sensitivity of ice to changes in the climate system all combines to make its understanding crucial in order to understand the future of the Earth system. GSFC's cryospheric research group has been the leader in providing the space-based view of the Earth, looking at it in ways that no other organization can. GSFC has produced algorithms, data sets, and information that have greatly enabled the broader scientific community to do its research, which in turn is reshaping scientific and societal understanding of the ice. ICESat was conceived and implemented at GSFC and is producing major advances in the observation and understanding of the polar regions. Algorithm development and data analysis are occurring in parallel with major efforts in developing the technology associated with laser altimetry.

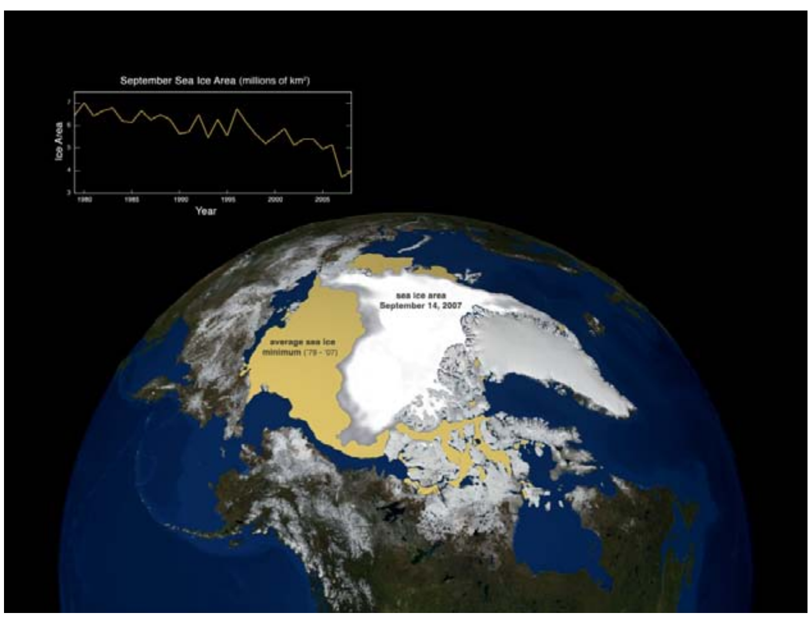


Figure 8. In 2007, Arctic summer sea ice reached its lowest extent on record - nearly 25% less than the previous low set in 2005. At the end of each summer, the sea ice cover reaches its minimum extent. The area of the perennial ice has been steadily decreasing since the satellite record began in 1979, at a rate of about 10% per decade. But the 2007 minimum, reached on September 14, is far below the previous record made in 2005 and is about 38% lower than the climatological average. *(Scanning Multichannel Microwave Radiometer, Nimbus-7, Special Sensor Microwave/Imager Defense Meteorological Satellite Program)*

The Goddard group addresses the following basic science questions:

Scientific Questions

- How will changing ice cover contribute to future sea level and over what time scales?
- Will there be catastrophic collapse of the major ice sheets?
- What will be the influence of changes in land ice on the climate system, the water cycle, and the biosphere?
- How will changes in sea ice affect climate and climate processes?

and has a strong heritage in using satellite data:

Heritage

- Major research accomplishments in ice sheets, sea ice, and terrestrial snow research.
- Home of the ICESat and ICESat-II missions.
- Research based on satellite visible/infrared imagery (specifically AVHRR, MODIS, Landsat),, satellite passive microwave data (specifically SMMR, SSM/I, AMSR-E), satellite radar and lidar altimetry (ERS-1/2, ICESat)
- Research based in airborne visible/infrared, passive microwave, radar and lidar altimetry instruments.
- Generation of algorithms and production of data sets for the community.
- Original development of passive microwave sea ice algorithms.

Furthermore, the activities of the cryospheric group have direct relevance to NASA HQ priorities and to the missions recommended by the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Central to at least two of the six NASA Interdisciplinary Science Focus Areas: Water and Energy Cycle and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
    - ICESat II (Ice, Cloud, and Land Elevation Satellite–II) [Decadal Survey timeframe: 2010-2013]
    - DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice) [Decadal Survey timeframe: 2010-2013]
    - LIST (Lidar Surface Topography) [Decadal Survey timeframe: 2016-2020]
    - GRACE II (Gravity Recovery and Climate Experiment-II) [Decadal Survey timeframe: 2016-2020]

To be able to maintain the present commitments, to support Aquarius and to participate in the design of the missions suggested by the NRC Decadal Survey, the Division proposes the hiring of three new scientists.

Planning for New Staff to Meet Future Needs:

- Sea ice scientist
- Ice sheet scientist
- Permafrost scientist

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

Mass Balance and Water Storage in Ice Sheets, Ice Caps, and Glaciers

Our studies of Greenland and Antarctic ice sheet mass balance, ice sheet dynamics, ice sheet history, and other glacier and ice sheet processes require extensive use of satellite data from radar altimetry, visible and microwave imagery and, more recently, ICESat laser altimetry – NASA's first satellite mission designed specifically to measure polar ice cover. In addition, we have led the way in developing precise airborne survey capabilities to enable measurements of ice sheet topography and elevation changes over small ice caps, significant portions of Greenland, and some actively changing areas in Antarctica. These airborne measurements were the precursor to ICESat and have also enabled verification of the satellite's data. By combining these activities with modeling and in-situ observations, we develop critical insights into the mechanisms that drive ice sheet and glacier behavior. Our glaciologists have uncovered the dynamics of dramatically changing ice streams in the West Antarctic and Greenland ice sheets, revealing new information about their behavior that has only recently been made possible by our remote sensing perspective. As a result, our scientists participate in and often lead major international polar science programs including the International Polar Year (IPY).

Our land-ice five-year primary focus will continue to be on determining how Greenland and Antarctic ice sheets contribute to sea level in a changing climate. However, we will also work to assess the mass balance of the smaller ice caps and glaciers as a complement to these ice sheet studies and will add staff to address ice sheet modeling needs. We will further strengthen our modeling capabilities to enable a comprehensive understanding of the changes in ice on Earth, applying this expertise as applicable to the ice cover on Mars or elsewhere in the Solar system in order to support NASA's initiatives. A major goal during the five-year period is development of the ICESat-II instrument and mission. In addition, we will extend our leadership in the analysis of radar altimetry data on ice sheets to include advanced processing of data from the European Space Agency (ESA) CryoSat-2 mission to enable new insights into processes that are important for understanding ice sheet changes. Partnering with colleagues at NASA's Jet Propulsion Laboratory, we will be developing our experience with Interferometric Synthetic Aperture Radar (InSAR) and applying these capabilities to the studies of ice sheet morphology and dynamics.

In the upcoming five years, we will prepare ourselves for ICESat-II, which will be led out of Goddard. Goddard cryospheric scientists provide the ICESat-II Project Scientist and Deputy Project Scientist, and several members of the ICESat-II Science Definition Team. We will furthermore seek participation in the upcoming DESDynI mission, as well as NPOESS, ESA's Cryosat, the Japan Aerospace Exploration Agency (JAXA)'s Global Change Observation Mission-Water (GCOM-W), and GRACE-II that have sensors on the platforms relevant to polar science.

Furthermore, the Goddard group is leading the Operation Ice Bridge mission, an effort to bridge the data gap between ICESat and ICESat-II using airborne measurements over the Greenland and Antarctic ice sheets as well as over sea ice.

The Role of Sea Ice in the Polar and Global Climate System

Sea ice—a key component of the ocean-ice-air system and a strong indicator of polar climate as well as global climate variability—is a major research topic within the Division. Our development and analysis of long-term sea ice records from passive microwave satellite observations has defined sea ice variability, including hemispheric, seasonal, and regional trends. Our scientists serve on the Aqua AMSR-E, Terra/Aqua MODIS, and ICESat Science Teams with responsibility for the sea ice algorithms and leading sea ice algorithm validation field campaigns,. One is the Aqua Project Scientist, and two are the ICESat and ICESat-II Project Scientists.

Our analyses of satellite data and our numerical models of ocean-ice-atmosphere interactions address the dynamic and thermodynamic processes associated with sea ice variability. Other efforts focus on the sensitivity of atmospheric and oceanic variability to polar sea ice conditions and feedback mechanisms, specifically, the relationships between interannual to decadal oscillations and hemispheric sea ice and SSTs, the response of sea ice and ecosystems to warming trends in the Arctic, the relationships between sea ice motion and sea surface winds, and the role of Arctic and Antarctic coastal polynyas in deep ocean water production.

Our five-year goals will add measurements and/or retrievals of sea ice thickness and snow on sea ice to our measurement capabilities. These measurements will allow us to monitor the 3rd dimension of the sea ice cover and will enable us to determine the sea ice mass balance. Technologies include ICESat, the ICESat-II, and Cryosat-2 combined with radiometry from AMSR-E and other sensors, such as Synthetic Aperture Radar (SAR) and scatterometry. Adding staff to offset anticipated retirements, we will take advantage of our strength in passive microwave remote sensing to seek opportunities on missions led by organizations other than NASA such as NPP/NPOESS or JAXA's GCOM-W, and we will pursue utilization of active sensors, such as SARs and scatterometers. We furthermore plan to position ourselves to take advantage of the opportunities the Aquarius mission will offer to study processes of sea ice formation, sea ice melt, brine rejection, and the implications on ocean circulation. We will further develop the linkages between these new measurement capabilities and numerical modeling to understand the detailed interactions between sea ice and climate, as satellite and model resolution and physics continue to evolve.

Furthermore, Operation Ice Bridge (mentioned above) has a specific sea ice component to monitor sea ice thickness changes in the Arctic and Antarctic oceans.

8.2.3 Terrestrial Water Cycle

The Terrestrial Water Cycle (TWC) is a fundamental component of the Earth system with a major impact on society. GSFC has played an important role nationally and internationally in TWC research and applications by providing the unique space-based view of the Earth's water and energy cycles as well as a unique terrestrial hydrologic modeling capability that merges these observations with predictive models. This leadership is largely a result of the presence of a critical mass of TWC scientists with a multi-decadal heritage of theoretical work on (mostly microwave) remote sensing, instrument and algorithm development in collaboration with co-located engineers, numerous field campaigns for validation and technology advancement, hydrological systems modeling and data assimilation, and demonstration of the impacts of satellite retrievals on our ability to understand and predict the hydrologic cycle.

The activities in this area deal with basic scientific questions:

Scientific Questions

- What are the causes of water cycle variations?
- Are variations in the global and regional water cycle predictable?
- What is the impact of variations of snowmelt runoff on the availability of fresh water?
- How are water and biological cycles linked?

The TWC group record is summarized below:

Heritage

- Research has been underpinned by:
  - -- Tropical Rainfall Measuring Mission (TRMM), Terra, Aqua (MODIS, AMSR-E, AIRS) and Aquarius.
  - -- Production of long-term global soil moisture and snow data sets for climate change studies using SMMR on Nimbus 7, Landsat, SSM/I, AVHRR, and GOES.
  - -- Model development to describe long-term trends in ground water, large-scale evaporation over land, and atmospheric response to variations in the surface energy and water budgets.

Its activities are directly supportive of NASA priorities and are well-connected with the missions recommended by the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Central to at least two of the six NASA Interdisciplinary Science Focus Areas: Water and Energy Cycles and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
    - SMAP (Soil Moisture Active/Passive) [timeframe: launch in ~2015]
    - GPM (Global Precipitation Measurement) [timeframe: in development]
    - SWOT (Surface Water/Ocean Topography) [timeframe: 2013-2016]
    - ACE (Aerosol-Cloud-Ecosystem) [timeframe: 2013-2016]
    - GRACE II (Gravity Recovery and Climate Experiment-II) [timeframe: 2016-2020]
    - SCLP (Snow and Cold Land Processes) [timeframe: 2016-2020]

To be able to maintain the present commitments, to support Aquarius and to participate in the design of the missions suggested by the NRC Decadal Survey, the Division proposes the hiring of two scientists.

Planning for New Staff to Meet Future Needs:

- Terrestrial water storage data assimilation and analysis expert
- Surface water remote sensing and modeling specialist

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

Our terrestrial hydrology research strives to understand and predict all components of the terrestrial hydrological cycle, over their broad range of spatial and temporal scales. This research therefore includes efforts to translate the remotely sensed measurements into geophysical properties such as soil moisture content, snow mass, precipitation, ground water, evapotranspiration, vegetation density, etc., and feed that information into land surface hydrological models. Key parameters in which we are involved in understanding are:

Soil Moisture

Soil moisture has been shown in model experiments to be a potentially important contributor to skill in the prediction of summer rainfall over continents. Soil moisture also plays a crucial role in vegetative processes, and it links the physical climate system (water and energy cycle) to biogeochemical cycles. Through numerous field and/or airborne campaigns, Division staff has convincingly demonstrated soil moisture remote sensing capabilities in terrain covered by thin or moderately dense vegetation (e.g. typical crops), using passive microwave emission radiometry at low microwave frequencies (1.4 to 3 GHz). This work has contributed substantially to the definition of the SMAP mission, a mission highlighted in the Decadal Survey. SMAP will provide the first systematic measurements of Earth's changing soil moisture and of the freeze/thaw status of the land surface. Together, these measurements link the water, energy, and carbon cycles over land and will open new frontiers in our understanding of how these global cycles interact in the Earth system. An immediate practical benefit of SMAP will be the improved accuracy of numerical weather prediction models that use the data.

Ground-water Mass

Division research uses space-based gravity gradiometer systems to measure changes in ground-water mass. These gravity field measurements are sensitive enough to detect the minute gravitational signature of the discharge/recharge of underground aquifers, as well as changes in soil moisture or snow water equivalent over continents. The current GRACE mission has demonstrated the ability to detect changes in mass distribution equivalent to ±1cm variation in water storage over a 500x500 km^2 area, with estimates validated against ground water wells and numerical ground water models. A recent Nature article documented dramatic declines in groundwater in Northern India. The five-year goal for this research includes implementation of the planned GRACE follow-on mission, which will provide the higher spatial resolution gravity measurement needed to resolve large basin aquifers around the globe. These measurements will provide important closure to basin-scale terrestrial hydrologic models.
An additional staff member will be required to support this task.

Surface Water Storage and Discharge

The capability to coherently monitor inland waters is an essential future development of Earth-system models that monitor the biosphere and land-to-ocean linkages. Accordingly, a five-year goal is strong participation in the SWOT mission recommended by the NRC Decadal Survey for the 2013-2016 timeframe. This surface water mission will provide global surface water elevation, discharge and lake storage information. This mission is expected to provide high spatial resolution data that can resolve the channels, floodplains, and lakes with a width of 100m or greater that contribute most of a basin's discharge, high temporal resolution data that can capture short flood events, and precise vertical resolution that will measure the subtle height changes that can be responsible for significant discharge. The SWOT concept is based on an interferometric SAR, which will yield a water map of volumetric gain or loss after each overpass. It will enable hydrologists to move beyond the point-based gauging methods of the past century to measurements of the spatial variability inherent in surface water hydrology. Global coverage will ensure that, despite local economic and logistic problems, all countries could access measurements critical for forecasting floods and droughts, both of which have dramatic economic and human impacts. An additional staff member will be required to support this task.

Snow Cover and Water Storage

The snow research activity seeks to quantify the extent, storage of water, variability, and albedo of global snow cover. Our research on instruments and algorithms for passive-microwave sensors, Visible Infrared (VIS IR) (AVHRR and MODIS), has a five-year goal of providing all-weather global snow cover and Snow Water Equivalent (SWE) observation capabilities (see Chapter 8.5.1). Understanding the extent, timing, and nature of snow cover throughout the world is essential to determining its role in the climate system. The need for operational global SWE data on continental, regional, to local scales is based on the importance of runoff from snow melt in the water budget and hydrologic dynamics in many locations. Our strategy for improving our ability to measure and predict SWE and impact of snow on regional-scale hydrology supports our participation in the SCLP mission, which is a third tier NRC Decadal Survey mission expected in the 2016-2020 timeframe. This mission concept combines active and passive microwave instruments to measure the snow pack. Laboratory scientists and others working in the Cold Land Processes Working Group are developing the SCLP concept. They are defining a comprehensive effort, which includes the Cold Land Processes Experiment (CLPX), and other community efforts. ICESat data is also being investigated for its application to snow thickness estimation.

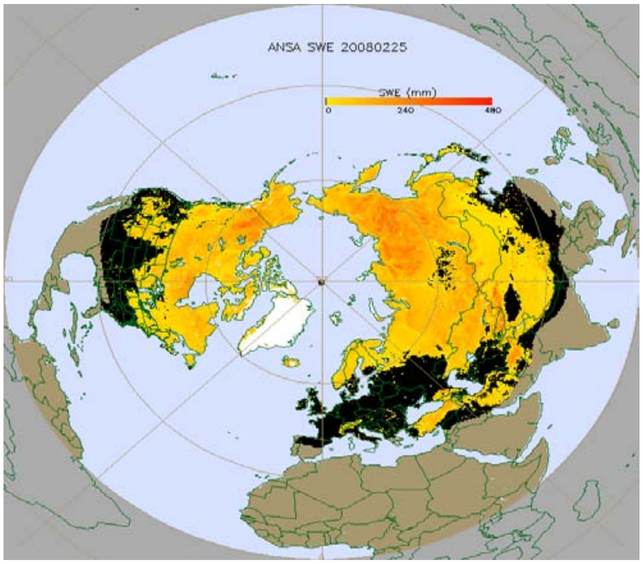


Figure 9. MODIS & AMSR-E snow maps are blended to create the Air Force - NASA Snow Algorithm (ANSA) snow product (funded by the U.S. Air Force. Shades of yellow represent different snow-water equivalents in each 25-km cell.

Land Data Assimilation Systems

The full terrestrial and global water budgets are exceedingly complex, and not all components can be adequately measured. As a consequence, Land Data Assimilation Systems (LDAS) are used to combine the measurements with the physical constraints of the terrestrial water budget as well as other physical constraints. A spectrum of land data assimilation systems are currently being used across the division depending on the analysis need, ranging from those that rely mainly on the integration of observed meteorological forcing [e.g., Global Land Data Assimilation System (GLDAS)] to those that use complex assimilation techniques (e.g., the ensemble Kalman Filter) to combine GLDAS-type integrations with satellite retrievals of surface state. The Land Information System is a computational framework that allows model integrations at scales down to 1km. These systems provide new approaches to the analysis of diverse water cycle data sources—satellite-based precipitation, radiation, and surface parameters, in addition to model-derived surface meteorology—in a computer forecast venue, and they support fresh water budget studies as well as a wide variety of applied uses. Our five-year goal is to continue improving our LDAS models, and to continue our close linkage with the research, observational, and numerical weather prediction communities. These models are maintained in such a manner as to enable parallel research activities with the other major land surface hydrology research laboratories around the nation. This will require continued improvements in our access to the high-end highly parallel processing support needed for the high resolution numerical LDAS models.

Model Analyses of Hydrological Linkages

Hydrological research in the Division is not limited to the quantification of the means and variability of the water cycle's key components. Division scientists use the measurements and data assimilation products in conjunction with Earth system models to perform extensive sensitivity analyses of the mechanisms underlying water cycle connections, variability, and predictability. Such analyses are designed to quantify, across a broad range of timescales, how much predictability in the water cycle can be extracted from knowledge of initial water cycle state. In so doing, the analyses identify the quantities that require the most attention from NASA measurement systems in regard to predictive skill – not just which water cycle components should be measured most accurately, but also the critical regions and timescales over which these component's variations are most important.

Global Water Budgets and Variability with Climate Change

The combination of the many observations of water cycle components, together with our advanced assimilation systems, allows us to evaluate the contribution of each water cycle component to the full water cycle. In particular, we are greatly improving our understanding of how to measure the individual components and the relative importance of measurement improvements to error reduction in the quantification of the full cycle. Our five-year goal is to continue this research to the point that we can define the needed capabilities for a complete global water cycle observational analysis system. Development of such a system would enable us to observe and understand the global water cycle well enough to be able to predict variability due to changes in weather and climate. If we can do this, then we should be able to predict changes in the availability of clean water due to future global ecosystem changes, weather and climate variability, and human impacts including population growth. These water cycle questions address the fundamental ability of Earth to support life. Within this broad area of inquiry are fascinating and important science questions, the answers to which will help us understand our future prospects.

8.2.4 Atmospheric Water Cycle

The breadth and depth of Atmospheric Water Cycle (AWC) research at GSFC cannot be found anywhere in universities and other federal laboratories. AWC research at GSFC dates back to the late 1970s beginning with development of NOAA's Television Infrared Observation Satellites (TIROS) Operational Vertical Sounder (TOVS) to measure temperature and moisture. Cloud radiation research began in the mid-1980s with the inception of the International Satellite Cloud Climatology Project (ISCCP) and the launch of the ERB (Earth Radiation Budget) satellite. The conception and formulation of TRMM in the late 1980s in the Laboratory for Atmospheres, and eventually the launch of TRMM in 1998, have vaulted GSFC to be the preeminent world leader in precipitation research. This leadership role will be maintained as GPM is expected to provide multi-year observations of global precipitation in the 2010 decade..

The AWC research has a very strong record in both experimental activities and research and analysis: (1) strong in-house development of measurement technology such as precipitation and shortwave cloud radars, lidars for water vapor, aerosols, clouds and wind, and cloud radiometers; and (2) strong record in cloud-resolving and mesoscale modeling whose approach is unique in emphasizing the creative use of NASA satellite data to improve model physics, to improve model simulations or forecast through data assimilation.

Scientific Questions

- What are the causes of water cycle variations?
- How do clouds, water vapor, and precipitation processes affect regional to global weather and climate?
- What changes to the atmospheric water cycle are expected in a warmer global environment, especially events with high impact on society such as hurricanes, floods, drought, and forest fires?
- How can we use satellite measurements to better understand the physical processes of the atmospheric water cycle and to provide better representation of these processes in global climate and weather models?

Heritage

- The research in this area began here in the late 1970s with NOAA TOVS.
- Continued through the 1980s with the ISCCP and the launch of the ERB satellite.
- TRMM was conceived here.
- GPM was conceived here.
- Extensive modeling efforts have been carried out here at the cloud scale, mesoscale, and global scale to study various processes affecting the AWC.

Relation to NASA Priorities and the NRC Decadal Survey

- Directly related to most of the six NASA Interdisciplinary Science Focus Areas. In particular to the Weather, Water and Energy Cycle, and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - o SMAP (Soil Moisture Active-Passive) [timeframe: 2010-2013]
  - o ACE (Aerosol-Cloud-Ecosystem) [timeframe: 2013-2016]
  - o PATH (Precipitation and All-weather Temperature and Humidity) [timeframe: 2016-2020]

- 3D-Winds (Three-Dimensional Tropospheric Winds from Space-based Lidar) [timeframe: 2016-2020]

Planning for New Staff to Meet Future Needs

- Precipitation and remote sensing expert
- Multi-platform statistical estimation of precipitation expert
- Microphysics of clouds and precipitation (joint with GMAO)
- Experimental scientist in radar and passive µ-wave remote sensing

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

Central to the global water cycle are the space-based Precipitation Measuring Missions (PMM), beginning with the TRMM, extended by the CloudSat mission, and now continued on with the GPM Mission. PMM provides not only state-of-the-art estimates of different types of rainfall, but also various products such as water vapor, cloud liquid water, cloud ice (from GPM), and vertical profiles of raindrop size distribution from the precipitation radar and the TRMM Microwave Imager (TMI), as well as the CloudSat radar. Combined with long-term records from ISCCP (see Chapter 8.5.1), the Earth Radiation Budget Experiment (ERBE), the High Resolution Infrared Sounder (HIRS), the Global Aerosol Climatology Project (GACP), and NOAA's TOVS, these measurements are critical in advancing understanding of fundamental aspects of the atmospheric water and energy cycle.

The conception and formulation of the TRMM mission in the late 1980s helped to focus the Division's precipitation research efforts and, as a result, Goddard has emerged as the preeminent leader in precipitation research. This leadership role will continue as new missions such as the GPM and NPP are planned to provide continuous multiyear observations of precipitation to the end of the decade. The CALIPSO and CloudSat missions (launched in 2006) have provided unprecedented data to measure the vertical distribution of properties of aerosols, clouds, and water vapor. The ESD will focus on the development of an advanced airborne wind lidar system and related technologies for water vapor transport, in anticipation of the 3D-Winds mission from the NRC Decadal Survey. An ESD priority is to promote close interactions with the international Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS) as a means of translating cloud-resolving model information into improved global climate model parameterizations.

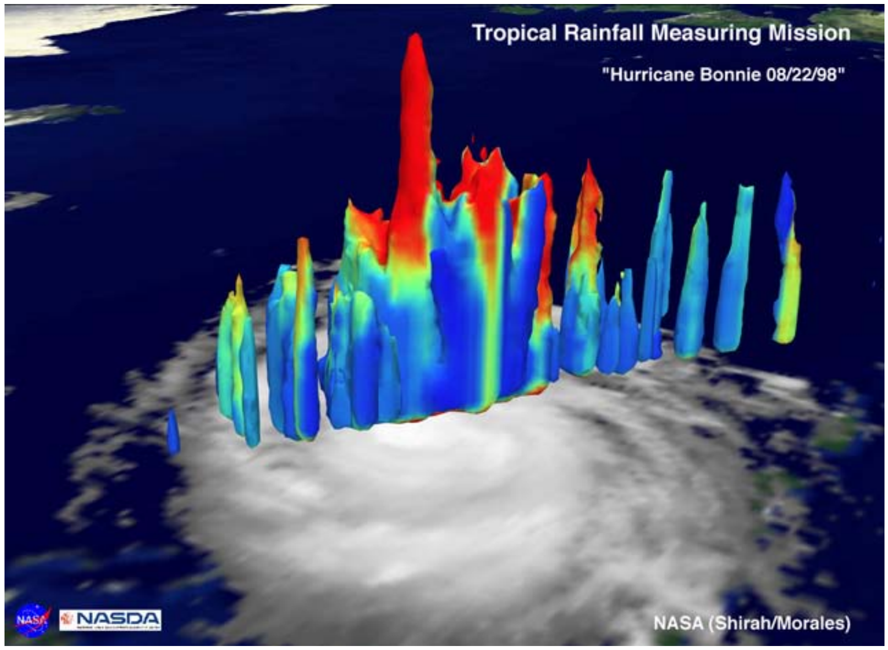


Figure 10. TRMM observations of Bonnie and other hurricanes show towering thunderclouds, called hot towers, that often signify the onset of intensification. (*Hurricane Bonnie, 8/22/1998; tallest tower is >15 km in height*)

In the next five years, the overall objective of atmospheric water cycle research will be to determine the correlated time and space varying characteristics of rainfall, water vapor, clouds and aerosols, and associated atmospheric diabatic heating, and how these characteristics are related to variations and long-term trends in the overall water and energy cycles. The main thrusts of our research effort on atmospheric water cycle are:

Precipitation, Cloud, and Water Vapor Climatology, Variability, and Trends

We will continue to improve and employ novel approaches to combine satellite rain information from multi-satellites in preparation for the eventual GPM rainfall product, which will consist of a core satellite with a dual-frequency precipitation radar, and a microwave imager, together with a constellation of microwave radiometers. The multi-satellite rain products will be used to validate model simulations of severe storms, spiral rainband structure in developing hurricanes, and to develop definitive climatology of mesoscale convective systems in different regions around the world. The global precipitation data set listed in Chapter 8.5.1 represents the global monthly average precipitation estimates for the period January 1979 to the present. This data set is a major component of the Global Precipitation Climatology Project (GPCP), established to develop global precipitation data sets using satellite and conventional observations.

The possibility of TRMM continuing to fly for the next couple of years, narrowing or even filling the gap between TRMM and GPM (scheduled launch in 2013), has offered an exciting opportunity for a unique long-term global precipitation data set to better define the detailed diurnal, and seasonal climatology of rainfall, and for determination of variability and trend in rainfall and water vapor, as they relate to climate change. Moreover, the possibility of overlapping observations by the TRMM and CloudSat radars will give a more complete picture of global precipitation in both liquid and ice phases. In addition to trend analysis of total rain, we will also focus on the long-term statistics of convective versus stratiform rain, cold versus warm rain processes, continental versus oceanic rainfall, mesoscale convective complexes, and their relationships with other components of the atmospheric water cycle, i.e., water vapor and sea surface temperature. In addition, GPM's focus on higher sampling rates for global precipitation, including especially solid precipitation over land and ocean in higher latitudes will provide unprecedented global data not only on total rain rate, but on rain types, and hydrometeor characteristics.   Such data products will be extremely important for precipitation research, and for climate change impact studies.

Cloud variability and trends will be documented in the ISCCP, Clouds and the Earth's Radiant Energy System (CERES), and MODIS data sets. Analysis of ISCCP-derived radiative fluxes will enable observed variations in the planetary energy balance to be associated with specific cloud types, and thus, physical processes and feedbacks. The combination of TRMM latent heating profiles with ISCCP and CERES radiative heating profiles will create the first long-term record of total diabatic heating variations that force observed circulation anomalies on interannual and decadal time scales.

Data Assimilation and Improved Climate Model Physics
Satellite rainfall, cloud, and water vapor products will be used for assimilation into the NASA GEOS-5 GCM for improving weather prediction and climate simulations. Unlike observations in clear-sky regions, rainfall data are difficult to assimilate because rain estimates from forecast models can have large biases. The PMM Science Team will provide leadership to the data assimilation community to explore innovative approaches to use rainfall data to improve atmospheric analyses and forecasts. These new approaches range from variational rainfall assimilation using the model as a constraint, to super-ensemble forecasting techniques. In addition, new information on drop size distribution and cloud liquid water from TRMM/GPM, will provide more information on the rain microphysics and latent heating profile with regard to fundamental processes in the atmosphere such as diurnal cycle, seasonal and intraseasonal variability. These processes need to be properly represented in order to increase reliability in long-term climate model projections. The resulting global analysis products will provide the most accurate estimates of long-term atmospheric circulation anomalies. They will be used to drive simulations of the column physics in climate models, which can then be directly compared to the satellite rainfall, cloud and water vapor fields to evaluate the fidelity of parameterized model physics and to provide clues for model improvements.

Clouds and Aerosols Interactions
Clouds and aerosols have been identified by the IPCC (2007) as two of the most crucial factors responsible for the uncertainties in model projections of climate change. The ESD has a long tradition of excellence in research of radiative transfers in clouds and aerosols. In the context of atmospheric water cycle, clouds and aerosols research are inseparable, because of aerosols' ability to modify cloud and rainfall formation (see discussion of aerosol/chemistry research in Chapter 8.1.2). In the near term, a major focus will be to conduct integrated satellite observation and modeling work over key regions, the so-called aerosol "hot-spot", where clouds and aerosols are expected to have large impacts on the water cycle. One of these is the Asian monsoon region, where aerosols from natural dusts and industrial pollution are increasing at an alarming rate, and where satellite analysis from MODIS, TOMS, TRMM, and field campaigns such as ACE-Asia and the Joint Aerosol Monsoon Experiment (JAMEX) have yielded some very promising results. Other areas of research will include the effects of biomass burning over the Amazon on South American climate, Saharan dust on the West African monsoon, and suppression of rainfall and tropical cyclone geneses over the tropical Atlantic and their impacts downstream in the Caribbean and the Southeast U.S. These studies should focus on the interaction between aerosols-cloud-precipitation, radiation and dynamics as prime drivers of the regional and global water cycle. The results will in turn provide a context for understanding observed multi-decadal variability in the interactions between GACP aerosol products, ISCCP cloud and radiative fluxes, and GPCP precipitation. We will continue to develop innovative measurement technology of lasers and lidars, radars for clouds, aerosol and rainfall measurements to augment and calibrate data from planned satellite missions such as Glory and ACE, including instruments for ice clouds [Submillimeter and Infrared Ice Cloud Experiment (SIRICE)], and a 3D Cloud-Aerosol Interaction Mission (CLAIM-3D) for lateral viewing of cloud-aerosol microphysics and also to maintain the strong collaboration with the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) programs.

Integrated Observations and Modeling
In addition to the aforementioned GEOS-5 global modeling effort on precipitation, clouds and aerosol (see also Chapter 8.1.1.2), modeling activities for atmospheric water cycle will focus on the improvement of cloud microphysics using cloud-resolving models such as cumulus ensemble models and large-scale eddy simulation models, to take advantage of the high vertical resolution data from CALIPSO and CloudSat, and other planned satellite missions. Modeling activities will be focused on improving the representation of atmospheric hydrologic processes including clouds, radiation, and aerosols, in climate models. Experiments and observation validations will be carried out to evaluate the ability of models to simulate fundamental phenomena such as the diurnal water cycle. As high performance computing resources continue to increase, multi-model framework such as embedding cloud-resolving models into climate models, will be pursued. These models will eventually lead to the development of non-hydrostatic cloud resolving, and coupled chemistry next-generation climate models to study scale interactions in global water cycle processes. On a longer time scale, ESD is working toward the development of the Earth System Model which links atmospheric physics, chemistry, land and ocean, and models.

Applications
We will enhance our effort in areas with potential applications to rainfall and water resource distributions. We will provide real-time data from NASA satellites, such as TRMM, AIRS, and QuickScat, and collaborate with scientists from other agencies to improve skills of numerical weather forecasts. Near real-time TRMM-based estimates of tropical cyclones, flood warnings, and land slide potentials will be provided to various disaster relief agencies in the U.S., and overseas where conventional information is lacking. We will collaborate with NOAA’s National Environmental Satellite Data and Information Service (NESDIS) to provide rainfall data to estimate flood potential in hurricanes. NASA’s TRMM Multi-satellite Precipitation Analysis 3-hourly global rainfall data sets will be made available to numerous groups and countries globally, to help in detecting floods and monitor rain for agricultural uses. Similar activities to transition Goddard’s developments in the remote sensing of clouds, water vapor, and radiation will be conducted as well.

8.3 Carbon Cycle and Ecosystems

The carbon cycle is an essential component of the Earth system and its evolution, in terms of both biology and climate. A key objective is to close the carbon cycle budget by reducing the uncertainties in its atmospheric, land and oceanic components. Disturbances by natural phenomena, such as fire or wind, as well as by human activities, such as forest harvest, and subsequent recovery, complicate the quantification of carbon storage and release. The resulting spatial and temporal heterogeneity of terrestrial biomass and carbon in vegetation make it very difficult to estimate terrestrial carbon stocks and quantify their dynamics. It is also imperative to learn more about less studied components of the carbon cycle including soil carbon and the impacts of melting permafrost, changes in wetlands and feedbacks with climate.

Carbon cycle and ecosystems research at GSFC consists of terrestrial carbon cycle measurements and modeling (includes terrestrial ecosystems and land cover and land use change), marine phytoplankton measurements and monitoring, atmospheric CO_2 transport models with links to terrestrial and oceanic sources and sinks, and atmospheric circulation models with links to surface properties. Related to the above efforts are the satellite data information systems and assimilation of carbon cycle processes into weather and climate models. GSFC is also the leader in lidar technology, critical for vegetation structure and biomass assessments, land and ocean ecosystem characteristics, and atmospheric CO_2 measurements.

The basic scientific questions that are being addressed by the GSFC group are:

Scientific Questions

- How are the Earth's carbon cycle and ecosystem changing?
- How will climate change influence carbon cycle, ecosystem sustainability, and biodiversity?

The record of the Division's activities in this area is summarized below:

Heritage

- Development and refinement of the coupled carbon cycle-climate models (Simple Biosphere Model version (SiB2)
- Development and validation of global land vegetation data records from Landsat, AVHRR and MODIS.
- Development and validation of ocean color data sets from SeaWiFS and MODIS.
- Sensor calibration and characterization to support Landsat from its conception and into the Landsat Data Continuity Mission (LDCM), MODIS, and VIIRS eras.
- Support for SeaWiFS, the Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies (SIMBIOS), MODIS (Aqua and Terra), ICESat, NPP, Earth Observing (EO)-1, ICESat and Spaceborne Imaging Radar (SIR)-C science.
- Development of lidar and radar techniques for vegetation structure and biomass assessment.

The Division intends to support a mission to measure CO_2 in the atmosphere, the LDCM and VIIRS on NPP.

The activities of the carbon cycle and ecosystems group are directly relevant to HQ priorities and to the missions proposed by the NRC Decadal Survey as outlined below:

Relation to NASA Priorities and the NRC Decadal Survey

- Carbon Cycle and Ecosystems is one of the six NASA Interdisciplinary Science Focus Areas. In addition, the activities of this focus area relate well with the Water and Energy Cycle and the Climate Variability and Change themes.
- Carbon Cycle and Ecosystems research is directly relevant to the following missions recommended by the NRC Decadal Survey:
  - SMAP (Soil Moisture Active Passive) [2015]. Important as input to carbon cycle and ecosystem models and assessing sustainability of ecosystems.
  - ICESat II (Ice, Cloud, and Land Elevation Satellite–II**)** [2015]. Useful for large area estimates of vegetation structure.
  - DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice) [2018]. Essential for accurate above ground biomass, disturbance and biodiversity measurements.
  - HyspIRI (Hyperspectral/IR Imagery) [2020]. Useful for vegetation physiology and function measurements, and high resolution low biomass estimates.
  - ASCENDS (Active Sensing of CO_2 Emissions over Nights, Days, and Seasons) [timeframe: 2020]. Essential for identifying locations and magnitudes of marine and terrestrial CO_2 sources, sinks, and atmospheric transport.
  - GEOCAPE (Geostationary Coastal and Air Pollution Events) [2020]. Useful for studying diurnal vegetation physiology and function measurements at low resolution over the entire globe.
  - ACE (Aerosol-Cloud-Ecosystem) [2020]. Essential for ocean phytoplankton and useful for land carbon and ecosystems measurements.
  - LiST (Lidar Surface Topography) [2020]. Essential for high resolution global vegetation structure (biomass) measurements.

To be able to maintain the present commitments, to support SMAP, ICESat II, NPP, and to participate in the design of the missions suggested by the NRC Decadal Survey, the Division proposes the hiring of five scientists.

Planning for New Staff to Meet Future Needs:

- Ocean color remote sensing expert
- Terrestrial carbon cycle and ecosystems modeler
- Sensor calibration expert (TIR expertise desirable)
- Carbon cycle and ecosystems remote sensing scientist algorithms expert
- Terrestrial ecosystems remote sensing data fusion expert

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

The largest and best understood of the factors that contribute to climate warming is the rapid and continuing increase in atmospheric concentrations of "greenhouse" gases; trace gases that are transparent to the Sun's shortwave radiation, but absorb longwave radiation emanating from the Earth's surface warming the atmosphere. CO_2 released by fossil fuel combustion and landcover change such as deforestation is the most rapidly increasing atmospheric greenhouse gas, and the one that is widely accepted as the largest contributor toward warming of the Earth's climate. On average, about half the CO_2 released into the atmosphere through human activities each year remains there, steadily increasing atmospheric CO_2 levels, now over 380 ppm, is more than 35% above the maximum levels of the past 400,000 years. The other half is being taken up by the Earth's oceans and land ecosystems and direct atmosphere-ocean exchange. There is much uncertainty as to the locations and mechanisms that take CO_2 out of the atmosphere and provide the service of ameliorating the increase in atmospheric CO_2. Will these sinks for CO_2 continue to operate in the future or will they reverse and aggravate the greenhouse warming trends? Answering this question is a scientific imperative of this century. Until we can locate these sinks and sources for CO_2, quantify their strengths, and understand their biological and physical mechanisms, predictions of future atmospheric CO_2 concentrations, hence climate change, will be unreliable. The U.S. Climate Change Science program has identified a number of specific science questions focused on addressing the carbon sink issues:

(1) What are the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?
(2) What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?
(3) What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?
(4) How do global terrestrial, oceanic, and atmospheric carbon sources and sinks change on seasonal to centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?
(5) What will be the future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases, and how will terrestrial and marine carbon sources and sinks change in the future?
(6) How will the Earth system, and its different components, respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?

8.3.1 Terrestrial Carbon Cycle

The uncertainties in carbon stocks and fluxes of carbon are much larger for the land than for the atmosphere and oceans. A number of mechanisms have been proposed to explain the inferred land sinks, including biomass accumulation due to land use activities and the responses of ecosystems to climate change. Satellite remote sensing has contributed critical information leading to new insights and represents the most promising approach for further improvements in understanding and monitoring the terrestrial carbon cycle.

ESD has an active group of terrestrial carbon cycle scientists with strong connections to the rest of the carbon cycle science community. Division activities include investigating the terrestrial carbon cycle at scales from short-term local to long-term global. Using existing satellite resources (e.g. AVHRR, MODIS, Landsat) and extensive field studies, Division members have developed indicators of vegetation activity, land surface carbon stocks, disturbance and fire activity (Figure 11). Division members are using computer models driven by remote sensing data to understand the process controlling ecosystem productivity and carbon fluxes over the past two decades. The advances gained from understanding recent phenomena are being used to improve model forecasts of the future. Collaborations within the ESD include the modeling of atmospheric carbon and the development of a unified land surface model (coupled water, energy, and carbon cycles) to incorporate requirements to address terrestrial carbon cycle studies. Paleovegetation studies have a key role to play in understanding the interplay between vegetation dynamics mediated by climate and the carbon cycle. Particularly important is the role of soil carbon, which represents 2/3 of the terrestrial carbon storage, accumulated over paleo time scales. Carbon currently stored in currently frozen soils is especially important and will be investigated. The Future development plans include field, aircraft and satellite measurements combined with coupled modeling and assimilation system to quantify air-land and air-ocean carbon fluxes. Scientists in ESD are working closely with scientists and engineers in the Solar System Exploration Division to develop laser technologies that can be flown in space and can be used to measure carbon stocks in vegetation and in the atmosphere. The need for these capabilities is explicitly addressed in the NASA HQ Roadmap for the Carbon Cycle and Terrestrial Ecosystems Program.

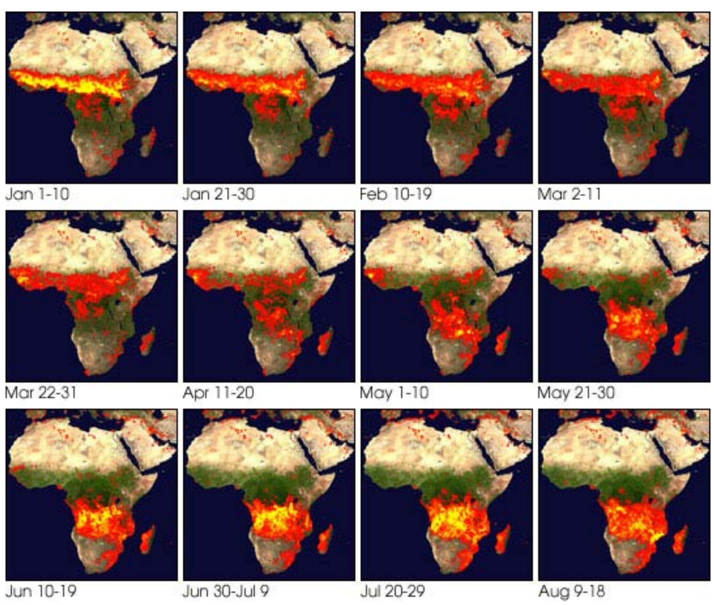


Figure 11. This series of images shows the seasonal fire patterns in Africa throughout 2005. The images are based on fires detected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites. Each image is a composite of 10 days of fire detections (marked in red and yellow) made by the sensors; the series includes images from every other 10-day period from January 1 through August 19, 2005.

In the next five years, we plan to ensure continued advances in carbon cycle research which include: the development of a coupled model and assimilation system to quantify air-land and air-ocean carbon fluxes; the study of the variability of trace gases in the atmosphere, and their dependence on biomass burning and land cover change; development of global disturbance maps at fine spatial resolutions (50m-1km); development of new techniques and algorithms to measure vegetation structure and functioning using new instruments on aircraft and space platforms; development of new ways of analyzing EOS long-term data sets for the purposes of extracting carbon cycle related information; the development of new carbon related missions under NASA's Earth Science and Application decadal survey such as DESDynI; and the development and science support for accurate ocean productivity measurements.

8.3.2 Terrestrial Ecosystems and Land Cover

Land Cover describes the distribution of vegetation and land types around the globe. It provides the lower boundary condition for atmospheric transport, and mediates biochemical exchange between the atmosphere and hydrosphere. In addition, since human populations live on the land, human appropriation of Earth's environment for food and fiber can be directly observed through changes in land cover (e.g. deforestation, urbanization, increases in irrigated agriculture, etc). Land cover and land cover change occur over a large range of temporal and spatial scales. For example, while boreal fires mark the landscape at scales of >100 km^2, human driven disturbance in third world countries often occurs at sub-hectare spatial scales, but when these disturbances are aggregated to regional scales they represent large impacts on the carbon cycling, hydrology and resources. The rate at which these changes occur fluctuates with climate and politico/socio/economic conditions, but it is the long-term trends that affect climate and the sustainability of resources needed to support human populations and natural ecosystems. It is for these reasons that the study of land cover and its changes often requires fine spatial resolution measurements over decades. Space-based observations are the only plausible method of monitoring land cover change processes at continental to global scales in a consistent way over annual to decadal time periods.

The Division has a long and productive history of developing satellite concepts and validating satellite algorithms to map land cover change over the entire period of record of land satellites. These capabilities have permitted us to map changes in ecosystems from regional to global scales. The Division is also engaged in modeling ecosystem processes and patterns in response to natural and anthropogenic effects. The research uses coupled ecosystem models and remote sensing observations to monitor and predict ecosystem change in a variety of vegetated systems: boreal, tropical, temperate, and semi-arid. Monitoring land cover change using satellite imagery reveals the extent and rates of natural and anthropogenic impacts on vegetation. The data for these studies come from Landsat, EO-1, Defense Meteorological Satellite Program (DMSP), and the NOAA polar orbiting operational satellites. The Division plays a leading role in Landsat and EO-1, in fact, we are hosting the Landsat Project Science Office (LPSO), responsible for ensuring the science integrity, including sensor calibration. Using high-resolution imagery, forest disturbance is being mapped across North America using decadal Landsat imagery as part of the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). A new project is focusing on correlating long-term trends in North American vegetation indices with changes in land cover, to separate climate-driven trends from human activities. Forest-cover change and disturbance are also being mapped in North America and northern Eurasia.

Our near-term goal begins with ensuring data continuity for coarse resolution (1 km) and higher (30 m) resolution sensors. These long-term, systematic measurements include data continuity from AVHRR to MODIS to VIIRS on NPP and later on NPOESS. Higher resolution data continuity resides in the Landsat series. Division efforts are required to ensure this long-term record continues and that it is appropriately calibrated and validated to ensure science goals are attained. For coarse resolution data, efforts will continue with MODIS on Terra (proposal pending), work on the NPP Project Science and NPP Science teams. For Landsat, a data gap looms with the failing health of Landsat 5 and Landsat 7, so LDCM is being carried forward in the near-term, and Division scientists have the responsibility for its scientific integrity.

Over the next five years, questions of terrestrial ecosystem and land cover change will be addressed by combining data from more than one sensor, either for current or long-term analysis. Opportunities for exploiting data fusion concepts will be sought out through ROSES. The Divisions unique capabilities for modeling electromagnetic energy interactions with vegetation will be exploited for this purpose. In addition, analyzing large numbers of Landsat or other higher resolution data sets simultaneously will facilitate analyses of regional to global ecosystem processes. We look to have global coverage capability early in the next decade to continue the assessment of decadal global land cover change. Over the next decade, there will be an evolution from land cover change analysis to the monitoring of ecosystem functioning such as productivity, stress, and structure. New technology is required to accomplish this. For example, imaging spectroscopy in both low Earth orbit and geosynchronous orbits and imaging lidar can provide the fundamental measurements required. To meet these needs, we are providing science support to the NRC Decadal Survey HyspIRI, GEOCAPE, DESDynI, and several Venture Class mission concepts.

8.3.3 Biological Oceanography

See Chapter 8.2.1.2 for details.

8.4 Climate and Weather Prediction

The linkage across the disparate fields of atmospheric, hydrological, and biospheric sciences comes through the interface between these disciplines: the atmospheric prediction models need oceanic and land surface boundary conditions, the ocean models need atmospheric wind stress, the biospheric models need rainfall, etc. These interface requirements are needed in the development of climate and weather prediction models, and this area is the true focus of interdisciplinary science. Ultimately, the interfaces must be represented within a completely integrated model – coupled ocean, atmosphere, land, sea-ice, chemistry, biosphere – with the system components fully interactive for a consistent representation of the Earth as an integrated system. Within the ESD, the weather and climate forecast groups link the other disciplinary activities and are the avenue for the development of this integrative Earth system model and an accompanying assimilation system, one of the major five-year goals of the Division.

Why should weather and climate modeling be done at NASA? NOAA and NASA have different missions. NOAA has operational climate, ocean, river, and weather observation and forecast responsibilities for the nation. NASA's SMD emphasizes remote sensing from space and attendant technologies to provide observations needed to understand the Earth system as a whole and the effects of natural and human-induced changes on the global environment. Though the agencies have distinct missions, they are united in their common reliance on access and use of global satellite data to accomplish their goals. ESD has led the development of the JCSDA. The mission of the JCSDA is to accelerate the quantitative use of satellite data in weather and climate prediction models for operational and research purposes. This collaborative approach represents a commitment of NASA and NOAA to focus on research and operational issues related to improving the forecast of high impact weather events and extending accurate weather forecasts to day seven and beyond.

NASA also has a distinct and formal role in weather and climate processes. NASA’s role in climate change can be traced back to the United Nations Framework Convention on Climate Change, which the United States was the first industrial country to ratify, and which states that its goal is to stabilize atmospheric composition to “prevent dangerous anthropogenic interference with the climate system” and to achieve that in ways that do not disrupt the global economy. This global agreement raises fundamental scientific and practical issues that must be addressed if decision makers are to have the quantitative information needed to most effectively carry out the treaty. Division scientists have contributed their climate modeling simulation to the latest IPCC, 2007 report and NASA is one of the core agencies in the multi-agency Climate Change Research Initiative (CCRI) to address climate change. The NRC Decadal Survey outlines a comprehensive set of satellite missions to study the Earth system with NASA a primary player.

NASA has been the primary source of information about global climate change. Our modeling efforts focus on the optimal use of satellite data. Assimilation tools are developed to optimize the use of the high-resolution information from satellite observations and diagnose their impact on predictions. Research-quality assimilated data sets, including clouds and precipitation, trace gas, aerosol, and climate products, and also ocean and land surface products, are generated for use by NASA instrument teams and for research analyses. To achieve its goals, strong collaboration exists between the Division's scientists and NOAA/National Centers for Environmental Prediction (NCEP) through the JCSDA, and with the other major modeling centers [National Center for Atmospheric Research (NCAR) and NOAA's Geophysical Fluid Dynamics Laboratory (GFDL)].

To address the cross disciplinary nature of long-term weather and climate modeling, the Division has two very active groups, one at GISS which focuses on long range climate modeling and one at GMAO which focuses on data assimilation, long-term weather and short-range climate prediction. These groups have active collaborations with other scientists in the Division to address discipline science questions. Our goal over the next five years is to strengthen and further these collaborations to benefit from the integrative power of models and assimilation system on the one hand, and the observational expertise needed for input to these tools on the other.

Strategic hires within ESD will be needed to address interdisciplinary modeling for the development of a comprehensive Earth system model and assimilation system. Expertise in global atmospheric and ocean model development is needed to replace scientists who have left the Division in recent years or who can be expected to retire in the coming decade. Although in recent years model development has shifted from the paradigm of an entirely internal development cycle to that of an integrative development, a paradigm that is facilitated by the integration of GEOS-5 under the Earth System Modeling Framework (ESMF), expertise is still required for the scientific integration of components and for developments that are not undertaken elsewhere to meet NASA's requirements. Because of our focus on the interplay of models and observations, hires are also required to address the observing system elements of our plans – better use of satellite observations as well as input to mission design. In particular, a critical hire is an experienced scientist to lead the development of infrastructure for OSSEs and the linkages and support for emerging mission concepts.

8.4.1 Climate Modeling and Analysis

Climate change has become the central organizing principle for Earth sciences for the 21st century. Human-made forcings of the global climate system are already large enough to dominate over natural forcings on decadal and longer time scales. It is imperative, for the sake of the public and the planet, that a better understanding be developed of what is driving climate change, what the impacts of climate change will be, and what humans can do to alter the magnitude and direction of climate change.

NASA has been a principal source of information about global climate change. This includes observational data about changing masses of the ice sheets and sea level, accelerating dynamics of ice streams, decreasing sea ice cover in the Arctic, poleward movement of forest cover, and other relevant measurements of global change. NASA has also been the principal source of data on changing climate forcings, such as solar irradiance, stratospheric ozone, volcanic aerosols, as well as human-made aerosols and gases.

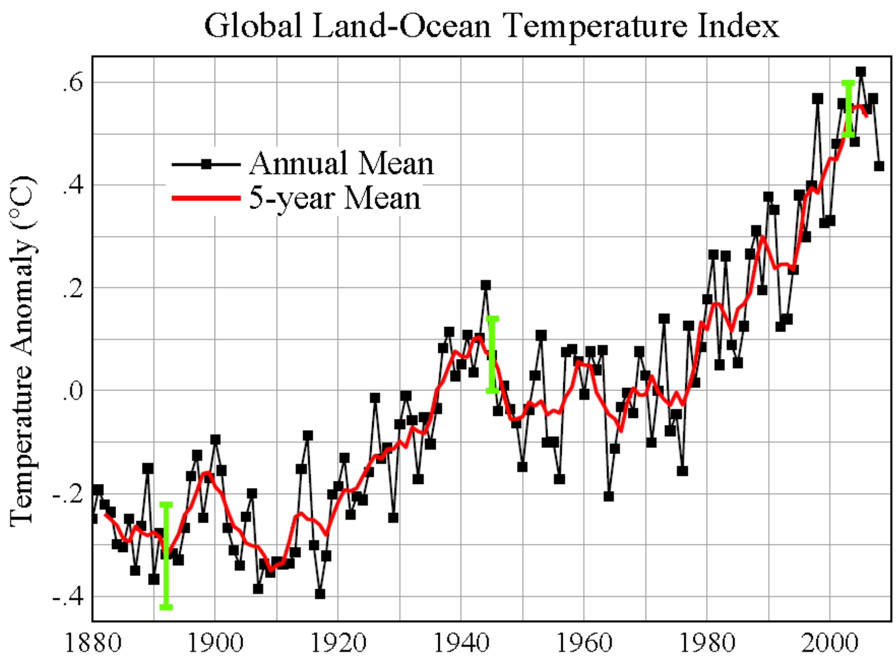


Figure 12. Global temperature is characterized by substantial interannual and interdecadal variability. But the temperature trend over the past three decades has rapid warming at a rate of almost 0.2°C per decade.

GSFC has been a leader in interpreting the causes of climate change and projecting the possible impacts of alternative scenarios for continued human emissions by developing and validating models and assimilation techniques. GSFC has been the world leader in providing climate data on changes of ice sheets, sea level, sea ice, land surface, vegetation, ozone and other gases, aerosols and other climate forcings, feedbacks and diagnostics. The basic questions being addressed by the ESD are:

Scientific Questions

- What is driving climate change?
- How does the Earth system respond to changes in climate and what are the associated feedbacks?
- What are the impacts of climate change?
- What can humans do to alter the magnitude and direction of climate change?

A summary of the record of the ESD in supporting this area of research is given below:

Heritage

- NASA has been the principal source of information about global climate change.
- GSFC, through the activities across the Earth Sciences Division, has been a leading organization in climate research.
- GSFC has been the principal organization to develop the analysis of data, to develop models and data assimilation techniques for the assimilation of the data and the validation of the models.
- GSFC has been the world leader in providing climate data on changes of ice sheets, sea level, land surface, vegetation, ozone and other gases, aerosols and other climate forcings, feedbacks and diagnostics.

The activities in this area of research are relevant to the HQ focus areas and in direct support of the NRC Decadal Survey's recommended missions:

Relation to NASA Priorities and the NRC Decadal Survey

- Central to all the six NASA Interdisciplinary Science Focus Areas, especially the Climate Variability and Change focus area.
- Directly related to all the recommended missions in the NRC Decadal Survey.

Planning for New Staff to Meet Future Needs:

- Climate modeler

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

Long-Term Climate Change

Climate simulations must cover the industrial era, because of the long response time of the ocean and the need for policy makers to consider anthropogenic effects. Paleoclimate history must be considered because of the insights and model tests that it provides. The climate simulations need to include high spatial resolutions, so that they can contribute to climate impact studies and to climate process studies on regional scales. Climate time scales require that the vertical extent of the model include the full ocean and the middle atmosphere, as well as the troposphere.

Our modeling emphasizes the role of climate forcings, defined with the help of outside experts, climate feedback processes, and climate diagnostics. NASA observations have given attention to natural and anthropogenic climate forcings. Quantitative understanding of forcings is needed to evaluate the effectiveness of climate mitigation strategies. Feedback processes need to be understood to make progress on the climate sensitivity issue – important feedbacks include those due to clouds, water vapor, and sea ice. Key climate diagnostics derived from satellite observations, analyzed with the help of appropriate modeling, can yield advances in understanding of climate change. Precise measurements of ice sheet topography provide one example of important diagnostics. In combination with modeling and field studies, these measurements allow investigation of possible non-linear responses of ice sheets to growing anthropogenic climate forcing.

In the future, a new approach is needed for climate model development. It is not practical for a single group to have expertise in all the components of a global model, as the models are becoming more complex and include more physical and biological processes. Models for long-term climate must extend from the deep ocean to the upper atmosphere, and beyond to the variable output of the Sun. Components of the global system that were once treated as specified boundary conditions or neglected altogether must now be simulated and allowed to interact with other parts of the model. Processes that need to be simulated include the carbon cycle in the ocean and on land, atmospheric gaseous composition, aerosol properties, and even heterogeneous chemistry.

One implication of this is the need for an open standard for building Earth system models; that is the objective of the ESMF project. The strategy for further model development is to take advantage of the improved modularity of the model to test and compare alternatives for key parts of the model. It still can be a major task to replace one module with another, because the climate model inevitably has been 'tuned' to be compatible with existing components. This implies that significant effort is required to test new methods, and it may not be easy to judge the ultimate potential of a new method from the first climate simulations.

8.4.2 Weather and Short-Term Climate

GSFC has provided leadership in the agency's modeling and data assimilation capabilities in support of weather and short-term climate research for the past two decades. This leadership has emerged because of the co-location with scientists leading or participating in all of NASA's satellite missions, the co-location of strong modeling expertise across several Earth science disciplines, and the proximity with NOAA's NCEP.

At the heart of the development of instrumentation and the launch of satellite missions is the integration of models and observations to make best use of diverse data streams—from multiple sensors and multiple platforms, remotely-sensed and in situ—to address the following:

Scientific Goals

- Interpret the information that the observations provide regarding the variations in our environment.
- Make estimates of the state of the Earth system that are consistent across space and time scales and across separate components of the Earth system.
- Enhance prediction of our future environment.
- Enhance our understanding of the possible link between climate trends and variability and extreme weather such as hurricanes and severe storms.
- Identify the merits of existing and the potential of new observations.

GSFC has a solid record of achievements as summarized below:

Heritage

- GSFC has provided leadership in the Agency's modeling and data assimilation capabilities for over two decades.
- These capabilities have demonstrated the usefulness of AIRS data in improving weather predictions and have been used to provide meteorological products for NASA instrument team algorithms—MODIS land surface, CERES, Microwave Limb Sounder (MLS), and Troposphere Emission Spectrometer (TES) products.
- MLS ozone.
- Altimeter.
- Soil moisture.
- These modeling and data assimilation capabilities are the basis for some of the very important research-to-operations transition activities with NOAA through the JCSDA.

The activities in this area are directly relevant to each of the HQ focus priorities as well as to many of the missions recommended by the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Modeling and data assimilation play an essential role in each of the six NASA Interdisciplinary Science Focus Areas, with a special role in the area of Weather, Climate Variability and Change, and Water and Energy Cycles.
- The NRC Decadal Survey identifies the importance of "models and data assimilation systems that allow effective use of the observations to make useful analyses and forecasts" and bemoans the fact that "the U.S. has lost leadership to the Europeans in the international arena in an array of pivotal capabilities ranging from medium range weather forecasting to long-term climate forecasting. Without leadership in these and other forecasting capabilities, we lose economic competitiveness."
- Directly relevant to GPM, SMAP, Aquarius, SCLP, NPOESS, NPP, ACE, ASCENDS, GEOCAPE, 3D-Winds, and the other missions promoted in the Decadal Survey.

To maintain the present commitments, to participate in the design of the missions recommended by the NRC Decadal Survey, the Division proposes the hiring of one scientist:

Planning for New Staff to Meet Future Needs:

- Atmospheric model development, especially an expert in model physics
- Earth system model expert to lead the development of an integrated model of the atmosphere, ocean, land surface, and biogeochemistry
- Ocean model expert

Descriptions of the characteristics for the near-term and long-term hiring priorities are given in Appendix C.

8.4.2.1 Assimilation

Assimilation synthesizes diverse in-situ and satellite data streams into a single product according to uncertainties in the input data sets and also in the assimilating model. The initialization of numerical weather prediction models has been the major driver for atmospheric assimilation development. An important spin-off application has been the generation of retrospective analyses of the historical data stream, providing details of climate variability and a record of essential climate variables. Ocean assimilation products now initialize ocean weather forecasts and seasonal predictions with coupled models, as well as improve estimates of ocean climate. Satellite altimetry makes global ocean state estimation both feasible and meaningful. Surface salinity measurements from space will be made more useful through the assimilation process. Assimilation also enables the development of climate data records from ocean color measurements. Land data assimilation has also matured, stimulated by the availability of satellite-derived soil moisture, ground water, surface temperature, and snow cover measurements.

Assimilation efforts in the Division focus on: (1) improvements in NASA satellite data utilization for scientific analyses and initialization of models used for prediction; (2) guidance on observing system development; and (3) production of research-quality assimilated data sets as climate data records. These efforts include the developments for meteorological, oceanographic, and land surface analyses, atmospheric constituent assimilation for air quality/pollution forecasts, and assimilation of ocean color measurements.

Assimilation efforts in the Division are especially focused on the use of new data types to enhance weather, air quality, and climate prediction. In the next five years, the focus will be on new NASA missions such as the upcoming NPP and NPOESS missions, on Aquarius, on SMAP, and on the priority missions identified by the NRC Decadal Survey. In addition, developments will be undertaken for currently available data types that are more difficult to process such as high-resolution imagery, cloud properties, and data in cloudy and rainy regions.

The atmospheric data assimilation system currently employed in our meteorological analyses is the GEOS-5 Data Assimilation System (DAS), a radiance-based analysis system [the Grid-point Statistical Interpolation (GSI) analysis] jointly developed with NCEP integrated with the GEOS-5 global AGCM. This system is being used, in collaborations through the JCSDA, to advance the use of hyperspectral data from AIRS and also the use of temperature retrievals from the MLS and ozone retrievals from MLS and OMI. In addition to advancing the use of these new data streams, the developments for AIRS and the Advanced Microwave Sounding Unit (AMSU) help prepare for the Crosstrack Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS) on NPP. Like AIRS, CrIS will provide information on ozone and the major greenhouse gases in addition to temperature and moisture soundings needed for weather prediction. The GEOS-5 system is also being used to prepare for the assimilation of ozone data from OMPS on NPP.

Among the most valuable data for process studies and climate trend analysis are the so-called reanalysis data sets generated by letting a fixed version of a numerical weather prediction/data assimilation system "sweep" through several decades of observational data. The Division has generated a new reanalysis of the satellite era (from 1979) using GEOS-5. MERRA (the Modern Era Retrospective-Analysis for Research and Applications) improves upon the hydrological cycle of previous reanalysis and produces a comprehensive product suite for water and energy budget analysis and for chemistry transport models. It will continue forward in time as a climate data analysis to complement the changing system used to improve weather forecasts.

Another focus of the assimilation efforts in the Division is the development of an OSSE infrastructure to investigate the potential of new missions. For many missions or new instruments under consideration, OSSEs provide a quantitative evaluation of the potential impact of the data, and a mechanism to examine trade-offs in requirements or design. Such experiments can also prepare for the assimilation of new data so that it achieves its potential impact quickly. The execution of a successful OSSE requires a specialized skill set, and this area is a core competency of the Division. Most of the observations currently used for weather forecasts have been simulated using a simulator tool and a nature run provided by the European Center for Medium-range Weather Forecasting (ECMWF). Adjoint tools, developed with the assimilation system to evaluate observation impacts on forecast skill, are proving to be a very efficient mechanism for calibrating the synthetic observations generated for the OSSEs. The Division's OSSE capability represents the state-of-the-art in the field. It is being used to contribute to 3D-Winds development as well as for other Decadal Survey missions.

Over the next five years, the atmospheric assimilation system will advance so as to bring in the time-dimension more effectively with a 4 dimensional variational (4D-var) approach. This is essential for using satellite data more effectively as these data tend to be distributed throughout the assimilation window rather than occurring just at the analysis time. A prototype system is currently undergoing testing. In the next five years, this system will mature in terms of the physics included in the tangent linear and adjoint models used in the 4D-var and an implementation that explicitly accounts for model error will be tested. We will continue to explore innovative approaches to use rainfall data and rain and cloud-affected radiances to improve atmospheric analyses and forecasts. We will also extend the OSSE capability to non-Numerical Weather Prediction (NWP) missions by focusing on some of the early missions identified by the NRC Decadal Survey, e.g., ACE and ASCENDS.

The ocean and land surface data assimilation capabilities focus on using satellite data to enhance seasonal prediction. The Division has pioneered advanced techniques such as the Ensemble Kalman Filter (EnKF) for the multivariate assimilation needed to take advantage of surface altimetry. The techniques developed for altimetry should also prove effective for ocean color data and the surface salinity data anticipated from Aquarius. Over the next five years, we will focus on making progress with these new data types, especially as they provide information on air-sea fluxes needed for carbon cycle and water cycle studies. We also plan to develop observing system simulation expertise to contribute to future mission design. The EnKF has also been developed to help in dealing with the highly inhomogeneous nature of the errors in land surface models, as well as the multivariate assimilation needed to take advantage of surface soil moisture and snow observations. The land surface assimilation efforts have particularly focused on making effective use of surface soil moisture retrievals from AMSR-E and on the assimilation of terrestrial water storage estimates from GRACE. Preparations are underway for the SMAP mission. After launch, we plan to generate a Level-4 assimilation product for SMAP. The combination of these activities within the Division places us in a unique position for advancing an Integrated Earth System Analysis (IESA) that is a consistent analysis across the various components of the Earth system.

8.4.2.2 Weather Prediction

The primary responsibility for obtaining routine meteorological observations and for providing model and data assimilation output for operational weather prediction in the U.S. rests with NOAA. However, for a number of reasons NASA plays an important role in assisting NOAA to reach its operational goals.

One reason is that future improvements in weather forecast skill are most likely to be achieved by improving observations and by using them better in a data assimilation context. Weather forecasting is largely an initial value problem, and beyond the three-day range, observations covering the full global domain are required in order to establish sufficiently accurate initial conditions. The only realistic way to obtain this global coverage is by using satellite data. NOAA maintains a constellation of operational meteorological satellites to provide input to their weather forecast models. However, NOAA and other operational agencies also routinely include data from many of NASA's research satellites in their weather forecast systems. Scientists from the Division are therefore working closely with their colleagues in operational agencies on testing impacts of new NASA data and on continually improving the use of existing NASA data in operational systems.

GSFC manages the development of future sensors and observatories for NOAA, thereby ensuring a continued transition of new technology to the operational systems. These efforts are generally managed out of the Flight Projects Directorate with support from the Applied Engineering and Technology Directorate. However, the ultimate success of these developments is determined to a large extent by having access to the scientific understanding and the modeling and data assimilation expertise represented in the Division. This will ensure that the requirements to which new systems are developed become not only technically and economically feasible, but also that they accurately represent the state of the art of scientific understanding and future user needs.

An important application of assimilation systems from a NASA perspective is that of observing system science. Observing system sensitivity tools based on adjoint methods are being used to evaluate the impact of different data types on weather forecast skill. These tools are used in tandem with Observing System Experiments (OSEs) (also referred to as data-denial experiments) to evaluate the current observing system from a weather perspective. The Division is participating in assimilation collaborations for the World Weather Research Programme (WWRP) The Observing System Research and Predictability Experiment (THORPEX), including a comparison of observation impacts through adjoint tools.

An important aspect of NASA's interest in weather forecasting is the intimate connection between weather and climate on the modeling side. Historically, the vast majority of three-dimensional general circulation models used for climate simulations have evolved from numerical weather prediction models. Increasingly, the international modeling community is calling for "seamless" modeling, where climate models are subject to the confrontation with data and are tested in forecast mode (both weather and short-term climate prediction) as a metric to assess the reliability of long-term climate predictions.

Currently, the Division is focused on improving the use of EOS data, particularly AIRS, MODIS, AMSR, and MLS, for weather prediction. One of the challenges is how to make best use of the huge volumes of data in a computationally efficient manner. As we move to higher resolution models, we are able to reduce the model biases and more effectively use the data. Over the next five years, the Division's two main foci in system development for weather prediction will be the implementation of 4D-var and the development of a high-resolution, global non-hydrostatic atmospheric model. The 4D-var system is in a prototype test phase. The non-hydrostatic model is undergoing testing, tuning, and further development at resolutions down to 3.5 km globally thanks to a collaboration between GSFC scientists and colleagues at NOAA's Geophysical Fluid Dynamics Laboratory. One key near-term development effort is in the computational area –

scaling the model to efficient performance on computers using tens of thousands of processors. Of course, at high resolution, the model physics need attention. Another major thrust over the next five years will be the use of a Cloud Resolving Model and the high resolution data from CALIPSO and CloudSat to help improve the moist processes in the global model. With improved models and a 4D-var assimilation system, we will increasingly bring the models and assimilation system to bear on design of the observing system to support weather prediction applications.

8.4.2.3 Subseasonal-to-Decadal Climate Variability and Prediction

One of the key questions that the SMD seeks to answer is how well transient climate variations can be understood and predicted. It is now clear that SST changes have profound impacts on seasonal-to-interannual and also on long-term hydroclimate variability in a number of regions throughout the world. There is also emerging evidence that in some regions land feedbacks may play an important role. For example, division scientists, investigating why droughts seem to be less predictable than wet conditions over the U.S. Great Plains, found that the changes in predictability are primarily driven by changes in the strength of the land-atmosphere coupling. There are, however, a number of uncertainties about the physical processes that link regional climate to remote SST changes, the strength and nature of the land impacts, and the predictability of regional hydroclimate variations on seasonal to decadal time scales. The Division's research addresses these issues.

The Division has developed advanced assimilation techniques to improve seasonal prediction skill by using the information in satellite altimetry. We have also shown that soil moisture data can significantly influence predictions of summertime precipitation over some continental regions. Our seasonal predictions are contributed regularly to the consensus forecasts at NCEP and at the International Research Institute for Climate Prediction. Collaborations with NOAA through its Climate Test Bed are emerging. Diagnoses of real-time drought information and seasonal drought forecasts from our ongoing seasonal climate forecasts are contributed to the U.S. Drought Monitor and the U.S. Seasonal Drought Outlook prepared by the National Weather Service Climate Prediction Center, the U.S. Department of Agriculture, and the National Drought Mitigation Center.

Division scientists have led the Global Land-Atmosphere Coupling Experiment (GLACE), a successful international project aimed at quantifying, across a broad selection of global climate models, the degree to which simulated precipitation responds to prescribed time series of soil moisture content. We are now helping to lead the GEWEX/Climate Variability and Predictability project (CLIVAR) GLACE-2, a follow-on, ambitious project examining, again with a wide variety of models, the degree to which monthly precipitation and temperature forecasts improve through the proper initialization of soil moisture. For the first time ever, a global consensus will emerge regarding the value of land initialization for forecasts, perhaps motivating national forecast centers to make full use of land moisture initialization in their operations.

Over the next five years, our modeling efforts will continue to explore the impact of coupled prediction strategies and observations on prediction skill at seasonal to interannual timescales, with a focus on identifying the role that specific observations play in extending prediction skill and on developing effective initialization strategies. Reducing model biases that inhibit skillful forecasts will require, among other things, model developments that improve the boundary layer processes at the air-sea interface. Research will also extend to the shorter (subseasonal) timescales, beyond deterministic weather, including phenomena such as the monsoons and the Madden-Julian Oscillation, which may be important to the evolution of El Niño. Model developments will be undertaken to improve the representation of all the major climate modes of variability.

On decadal timescales, we will focus on understanding the sources and predictability limits of long-term droughts, assessing the nature and predictability of Pacific Decadal Oscillation (PDO)-like SST variations and of Atlantic Multi-decadal Oscillation-like SST changes, with a focus on the role of the thermohaline circulation (the Meridional Overturning Circulation). We will also develop effective coupled model initialization strategies. On these timescales we also plan to undertake simulations and predictions using the GEOS Chemistry-Climate Model (GEOS CCM). We will use the GEOS-5 model and the GEOS CCM in simulations to contribute to the collaborative Coupled Model Intercomparison Experiment as a prelude to possible contributions to the next IPCC assessment report.

The use of high-resolution models will allow us to undertake regional climate prediction, now usually undertaken with limited regional climate models or with statistical downscaling techniques. Another aspect of GEOS-5 is its utility as both a weather and climate model. We will use high-resolution climate simulations to investigate the impacts of climate on weather extremes such as tropical storms.

8.4.2.4 Prediction of Constituents – Chemical Weather Prediction

The assimilation and prediction of atmospheric constituents leverage from and augment the meteorological data assimilation system. In GEOS-5, ozone is assimilated in a multivariate framework along with temperature, moisture, and other meteorological data. Ozone column data from SBUV and OMI are assimilated along with profile data from EOS-MLS. In GEOS-5, the ozone assimilation will prepare for use of OMPS and CrIS data from NPP. Future development will incorporate increasingly comprehensive chemistry modules throughout the atmosphere, treating a large number of gases and their interactions with the atmospheric radiation balance. The same models are being used in chemistry-climate mode, to address questions related to past variations of ozone and their impact on the climate, as well as future prediction.

Tropospheric constituent modeling, including aerosols, is motivated by the radiative impacts on the circulation and by the important impacts of pollution on human life and ecosystems. Currently, carbon monoxide and several types of aerosols, tagged according to their sources, are used to support field campaigns. Support of the TC^4 mission in 2007 and the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) mission in 2008 gave considerable exposure to Division products and capabilities, demonstrating the realism of many aspects of inter-continental transport predictions in the analyses and forecasts. We are expanding the assimilation capability of the GSI system to include tropospheric constituents in order to monitor and predict pollutant distributions that are related to air quality. GEOS-5 will be augmented to assimilate aerosol data from a number of EOS A-Train instruments, such as MODIS, OMI, and CALIPSO, as well as from historical observations (TOMS and AVHRR). Scientific analysis of the aerosols will include studies of their effect on the atmospheric hydrological cycle. Consistent with the nature of most EOS observations of CO, NO_2 and other species, which contain geophysical information in the middle troposphere and higher, we will focus our study of tropospheric pollutants on long-range transport. Research will also focus on inclusion of the carbon cycle, with the intention of assimilating a range of observations of CO_2 and other relevant parameters, and of developing inversion techniques to infer surface sources and sinks from upcoming missions.

As for meteorology, historical (retrospective) analyses of atmospheric constituents are important for studies of variability in aerosol and trace gas distributions. The Division is currently building upon the meteorological analysis and the software infrastructure of the GEOS-5 Data Assimilation System used for MERRA to produce consistent distributions of aerosols and trace gases as a phased approach to developing an IESA. These “analyses” will focus on the EOS era since the EOS observations can be used for evaluation of the model-generated products.

8.5 Managing and Analyzing Data

The Division plays a leading role in the development and evolution of science data systems to generate and manage Earth system science data and information. ESD does cutting-edge research in the form, nature, and structure of large data systems, as evidenced by the various data systems listed below, each of which represents a unique research effort. Thus, rather than the “one size fits all” model of the original EOS data information system, ESD has presented to the research community many models of what a data system can be, and this has immeasurably enriched the knowledge of data systems.

Our data system capabilities include science algorithm development and integration, data set generation and reprocessing, archive management, data search and access services, and data distribution. We are active in the development and application of advanced capabilities that promote the discovery and maximize the availability and usefulness of science products. There is an extensive outreach effort including science conferences and workshops to build awareness and use of the available products and services.

In addition to managing, producing, and distributing data sets, ESD performs original applied research in computer science areas such as artificial intelligence, data compression, computer graphics, and image processing that provide both short-term and long-term benefits to NASA data and information systems. The ESD develops advanced computer data acquisition systems to meet the research needs of oceans, weather, land, climate, and hydrology and develops advanced data storage, data compression, and analysis techniques and distributed system architecture technologies.

8.5.1 Data Management Focus Areas

The Earth Science data management capabilities at Goddard are categorized into one of five focus areas: Data Discovery, Long-Term Data Records, Mission Data Products, Model Products, and Other Data System Capabilities. The focus areas are intended to highlight the diversity of capabilities enabled by ESD science data systems and/or products.

A brief description of the overall functional scope, IT capabilities, and systems capabilities is provided for each focus area. Specific data system capabilities are briefly identified (see tables below). The focus area categorization is approximate as many of the data system capabilities could be assigned to multiple focus areas. The selection criterion is to include data system capabilities that have an operational emphasis i.e., whose principal purpose is to carry out the operational[1] support[2] of Earth science data.

Data Discovery

Data Discovery includes suites of software applications that enable users to uniformly find, access, and use resources (data, software, documents, and image products and services) from a collection of distributed product repositories and service providers. It unites services and/or multiple repositories. The typical IT functionality includes: Web services and other software to register, find, and access widely-distributed science products using a community-based data model for uniformity; interactive tools based to allow the selection, visualization, and analysis of data; and community-based science analysis libraries.

[1] Attributes of an operational system: primary purpose to support science data and information products from Earth and space science missions, instruments, and models; and designed to meet requirements for schedule, timeliness, functionality, reliability, and quality.

[2] Support includes: data acquisition, processing/modeling, quality assessment, validation, archive, access, discovery, distribution, and user support; mission operations; algorithm and systems development, integration, and testing.

Data Discovery Capabilities	Content
CEOS IDN - Committee on Earth Observation Satellites International Directory Network - http://idn.ceos.org/	Gateway to global Earth Science data (supported by GCMD)
GCMD - Global Change Master Directory - http://gcmd.nasa.gov/	Summary descriptions of 21,000+ Earth-Sun Science data sets and 2,000+ related services; 130+ data portals.
GES DISC – Goddard Earth Science Data and Information Services Centers – for example see A-train Data Depot - http://daac.gsfc.nasa.gov/atdd/	6 DISCs: Atmospheric Composition, Atmospheric Dynamics, A-Train Data Depot, Hydrology, Modeling and Precipitation. Giovanni: data visualization and analysis application Mirador: text-based data search application.

Long-Term Data Records

Earth and space observing satellites have been flown by NASA since the mid-1970s. After launch scientists continue to develop algorithms and explore techniques for improving the data obtained from the sensors. This effort often extends well beyond our own satellites and sensors to those launched by other organizations – both domestic and international. Over time, the collection and reprocessing of the data from these early sensors and the process of combining data from more recent sensors with older data has led to the development of what is called "long-term data records."

The development of long-term satellite data records is time consuming, specialized work. Knowledge of both remote sensing and sensor performance is required, and these data sets also incorporate ground-based measurements. The ESD develops, operates, and maintains a number of data systems that support data acquisition, data integration, processing/reprocessing, science algorithm development, data analysis and validation of long term data records spanning multiple missions, instruments and ground validation. The data system capabilities scope for Long Term Data Records is similar to that described summarized in the Mission Data Products focus area (see next table).

Science Area	Long-Term Data Records	Data Sources
Atmospheric Composition	Satellite ozone data sets – total ozone and ozone profile data set since 1970, surface UVB and aerosol absorption data since 1978. (http://jwocky.gsfc.nasa.gov)	SBUV, TOMS, OMI
	Global Aerosol Climatology Project (GACP) data set since 1981. (http://gacp.giss.nasa.gov)	NOAA/AVHRR
	Aerosol products for land and ocean since 2000. (http://ladsweb.nascom.nasa.gov/)	Terra, Aqua, MODIS
	Aerosol products from ground-based sunphotometer network, since 1993. (http://aeronet.gsfc.nasa.gov/) and micropulse lidar network, since 2000 (http://mplnet.gsfc.nasa.gov)	AERONET MPLNET
Global Water Cycle	Global precipitation data sets – monthly since 1979, daily since 1997 and 3-hourly since 1998. (http://precip.gsfc.nasa.gov)	TRMM, SSM/I, geosynchronous IR observations, TOVS/AIRS data, AMSR, AMSU and rain gauges
	ISCCP cloud products since 1983. (http://isccp.giss.nasa.gov)	International constellations of weather satellites
Global Carbon Cycle	Satellite ocean color and biology data sets – global ocean chlorophyll concentrations, optical attenuation coefficients, and water-leaving radiances beginning in 1996. (http://oceancolor.gsfc.nasa.gov/)	Routine global data from OCTS, SeaWiFS, MODIS; Sparse global sampling from CZCS (1978-1986)
	Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI) data set since 1981.(http://glcf.umiacs.umd.edu/data/gimms)	NOAA/AVHRR
	Land long-term data record (Land Surface Reflectance) since 1981 (http://ltdr.nascom.nasa.gov/ltdr/ltdr.html)	NOAA/AVHRR
	Land surface albedo since 2000 (http://ladsweb.nascom.nasa.gov/)	Terra, Aqua, MODIS
	Global Land Survey (GLS) USGS/NASA partnership to generate global satellite data sets to support measurement of Earth's land cover and rates of land cover change. Calibrated data sets exist for ~1975, ~1990, ~2000, & ~2005. (http://gls.umd.edu/)	Landsat MSS, TM and ETM+ (GSFC does the scene selections and ensures the radiometric and geometric calibration.)
Climate Variability and Change	Global radiation budget data sets – short-wave and long-wave radiative fluxes at the surface, top-of-atmosphere, and other levels since 1983. (http://isccp.giss.nasa.gov/projects/flux.html)	ISCCP data set combined with TOVS, SAGE, TOMS, and other satellites
	Total solar irradiance since 1978.	Nimbus-7 ERB,ACRIM I, II, ACRIM III, SORCE, SOHO/VIRGO
	Sea Ice extent, concentration, and type (ESMR since 1973; SMMR since 1978).	ESMR (extent only), SMMR, SSM/I, and AMSR
	Ice sheet elevation changes since 1978.	SeaSat, ERS-1/2, Envisat, ICESat, airborne laser altimetry
	Spatial extent and water equivalent of snow.	AVHRR and MODIS SMMR, SSM/I, AMSR

Mission Data Products

Science Product Generation: Inputs minimally processed instrument data and transforms those data into progressively more advanced science products usable by the science community. Modifications include: instrument error correction, flat fielding, calibration, geo-location, re-sampling, coordinate transformation, applying science algorithms to transform from instrument counts to physical parameters such as sea surface temperature, radiant flux, land cover usage, etc. Typical Information Technology (IT) functionality includes: high-volume throughput, days turnaround time with a few near-realtime turnaround times, typically run at “keep-up-rates” aligned with science mission acquisition rates, akin to factory production, operational reliability high, development environments are often parallel and duplicative to allow science algorithm upgrades while not disrupting ongoing operations, not typically intensive Central Processing Unit (CPU) usage rather volume driven, not typically highly interactive to an external science community.

Science Product Archive and Distribution: Scope consists of large volume, permanent, remote sensing and in situ data stores, long-lived archives of remote sensing and in situ scientific data. Responsibilities include long-term stewardship of data, creation of tailored value-added products for the broad science community or the public. Typical IT functionality includes: Highly interactive services to the general public, including the scientific community providing substantial, Web-based tools for search, access, distribution, sub-setting, product tracking, community problem resolution, supported by intensive record keeping. Near-realtime responsiveness is required to the external users for search, order, subset, display, value-added production, etc.

Mission Data Product Capabilities	Missions Support
Atmospheric Composition Processing System (ACPS) (http://macuv.gsfc.nasa.gov/)	Aura (OMI) processing, NPP (OMPS) product assessment/validation [future mission]
AVDC (Aura Validation Data Center) - http://avdc.gsfc.nasa.gov/	Aura instrument validation
GES DISC - multi-mission archive and distribution; AIRS processing. - http://daac.gsfc.nasa.gov/	Aura (HIRDLS, MLS, OMI, SORCE); Aqua (AIRS), TOVS; OMI, MLS, CloudSat, CALIPSO, MODIS, POLDER; GEOS-5 (fp), MERRA, GLDAS; TRMM (LIS, TMI, VIRS)
Glory Processing System [future mission] - see Glory science page - http://glory.giss.nasa.gov/	Glory (APS)
GLAS Atmosphere Processing - http://icesat.gsfc.nasa.gov/missops.php	ICESat (GLAS)
LAADS (MODIS L1 & Atmospheres Archive and Distribution System) - http://ladsweb.nascom.nasa.gov/	Aqua & Terra (MODIS)
Land PEATE (Product Evaluation and Algorithm Test Element) - [future mission], access to site to science team members http://landweb.nascom.nasa.gov/cgi-bin/NPP/NPPlogin.cgi	NPP-VIIRS [future mission]
MODAPS (MODIS Data Processing System) - https://modaps.nascom.nasa.gov:8499/	Aqua & Terra (MODIS)
MPLNET (Micro Pulse Radar Network) - http://mplnet.gsfc.nasa.gov/	AERONET, CALIPSO, ICESat (GLAS)
OCDSPS (Ocean Color/SST Data Processing System) - http://seawifs.gsfc.nasa.gov/	MODIS (Ocean Color, SST), SeaWiFS. CZCS, MOS, OCTS, Aquarius [future mission]
PPS (Precipitation Processing System) Multi-Mission - http://pps.gsfc.nasa.gov/	TRMM (LIS, TMI, VIRS), GPM [future mission]

Model Products
Systems used to generate model output are typically intensive computing environments supporting multiple CPU usage of Earth system science models. Model development is repetitive with tests and changes happening dynamically but not typically aligned with satellite acquisitions in keep up rates, although this can happen with some field campaign supports. Near-real time model runs produce analysis data products as well as forecasts at regular time intervals. Very long range model runs produce multi-year or decade "reanalysis". Typical IT functionality includes: large scale computing systems coupled with high speed disk storage; locally developed and community developed models; primarily batch job scheduled (interactive to a limited expert modeling scientific community); and, with increasing collaboration among model developers, adding components to Earth system science models.

Modeling	Content
GEOS-5 (Goddard Earth Observing System Model) Processing System - http://gmao.gsfc.nasa.gov/systems/geos5/	Forward processing (analysis and forecast), MERRA (reanalysis)
GLDAS - http://ldas.gsfc.nasa.gov/GLDAS/docs/news.shtml	1° 1979-present Noah, CLM, and Mosaic LSMs, a 0.25° Noah LSM, and a 0.25° 2001-present of the Noah LSM
LIS (Land Information System) - http://lis.gsfc.nasa.gov/	Land surface models: NCAR Community Land Model (CLM); community Noah land surface model; and Variable Infiltration Capacity model (VIC).

Other Data System Capabilities
There are other data system capabilities provided within the ESD that do not necessarily fall within the other four focus areas. These include near real time product generation, product acquisition, and validation in direct support of NASA science missions, science applications, and science product generation from external missions. Functions and IT capabilities are similar to those listed under Mission Data Products.

Other Capabilities	Content
MODIS-RRS (Rapid Response System) - http://rapidfire.sci.gsfc.nasa.gov/	MODIS jpeg and GeoTIFF imagery
LEDAPS (Landsat Ecosystem Disturbance Adaptive Processing System) - http://ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica2008.html	Landsat vegetation disturbance maps
TRMM Flood / Landslide - http://trmm.gsfc.nasa.gov/publications_dir/potential_flood_hydro.html	TRMM
TRMM Ground Validation (radar) - http://trmm-fc.gsfc.nasa.gov/index.html	ground radar collection and processing

8.5.2 High Performance Computing

High performance computing is the life-blood of numerical modeling for climate, weather, the space environment, and solid Earth science. High performance computing also enables development and use of sophisticated data assimilation techniques, leading to enhanced exploitation of the observations made by Earth observing satellites to better understand the Earth as a system, including the atmosphere, oceans, land, and the solid Earth. Numerical models also are used as part of OSSEs and in support of scientific field campaigns. The models we will deploy in the future will demand more computational power than those we use today. They will have more complex physics, they will run at higher resolution, and we will need to make far more runs than we do today. In addition, we need to return results to the scientists faster than we do today.

Currently, the Agency provides leading-edge computing platforms through two primary sources: the NASA Advanced Supercomputing (NAS) facility at Ames, and the NASA Center for Computational Sciences (NCCS) at GSFC. In 2008, Earth science applications used approximately 65 million processor hours of computing power at these facilities, and produced over a petabyte of scientific and observational data. To execute the envisioned program of Earth science research in 2009 and beyond, substantially more computing power and data storage will be needed, along with enhanced capabilities to make NASA models and scientific data accessible to our research partners. A recent analysis of computational requirements for NASA Earth science estimates that by 2013 Earth science applications will require close to 900 million processors hours annually, which is approximately 80% of the total SMD requirement. (For further details, see the *Earth Science Modeling and Assimilation Panel Report of the SMD Requirements Workshop, August 2008*.)

The NCCS has analyzed the science requirements, technology trends, and budget expectations to develop a roadmap for NCCS systems. In summary, the NCCS envisions providing systems in 2013 with the following capabilities:

Computation

- 1.2 Teraflops of sustained processing power, estimated to require on the order of 120,000 cores at the anticipated future processor speed
- Enhanced software tools to exploit multi-core architectures
- Increased I/O rates to meet model execution requirements
- 250 Terabytes of random-access memory
- Ability to support larger numbers of jobs using on the order of 1000 processors
- Ability to support very large jobs using on the order of 10,000 processors

Storage

- 45 Petabytes of disk storage to keep data on-line for 1 to 2 months
- Enhanced global file system
- 60 Petabytes of archival storage
- Enhanced data management

Supporting services and systems

- Networks operating at multi gigabits/second
- 250 Teraflops for Analysis and Visualization
- Enhanced Analysis and Visualization tools
- Enhanced portals for external access to computing, data, and analysis

In addition, there is a need for a program of exploratory research into the application of advanced and innovative computing architectures to Earth science models. This includes exploration of the potential of Graphics Processing Units and Cell Processors to dramatically increase throughput per dollar.

To assist scientists in using the supercomputing facilities at Goddard and Ames, SIVO's Advanced Software Technologies Group (ASTG) provides a number of software and hardware support services to the community. The functions of SIVO are described in Chapter 8.5.3. ASTG Services include Level 2 help desk support to user training, code migration, performance tuning, parallelization, algorithmic development, software engineering, and code modernization. SIVO works closely with the NCCS to assess code performance and system configuration as new hardware systems are integrated. Additionally, SIVO supports developmental projects to research beneficial impact of emerging technologies on Earth science code performance and advancing software tools to enhance community use of NASA models.

8.5.3 Advanced Software Development

The Earth System Modeling Framework (ESMF)

Applications software is at the core of computational modeling and serves as the interface between the scientist and computer. The challenges inherent in modeling weather, climate, and the solid Earth require the integration of model components developed by a variety of research groups, thus enabling the notion of "Earth System Science." The ESMF has been successful in allowing weather and climate models from different researchers to operate together on parallel supercomputers, enabling comparison of alternative scientific approaches and ultimately improving predictive capabilities. ESMF also provides shared infrastructure which enables high performance in a portable manner across a variety of mechanisms.

Software Integration and Visualization Office (SIVO)

It is SIVO's responsibility to provide leadership to the Division and to the Directorate in addressing the issues of cost, risk, complexity, and performance of large numerical modeling codes. Between now and 2015, the biggest challenge will be adapting legacy codes to take advantage of new, complex architectures and customized architectural features. The growth of multicore systems presents a major challenge for scalability of Earth system modeling codes. Load imbalances and communication overhead will be exacerbated as parallelism requirements and the number of processors and cores increase. By 2015, the computing software and hardware must be able to support a factor of two improvement in horizontal resolution.

9. Instruments, Technology, and New Missions

Space missions are the main mechanism through which NASA gathers new observations to attack the science questions. Missions are also a major source of funding for ESD personnel and the GSFC. Winning future mission work is critical for the ESD. The Division has a long history in the development of UV/visible-, lidar-, and microwave-instruments and remote sensing.

As mentioned in Chapter 3, in order to win missions, the ESD's scientists work together with engineers to develop new concepts and design new instruments not only for space missions, but also for ground-, balloon-, and aircraft-based observations. The latter serve as steppingstones in the development of the spaceborne instruments, their calibration, and validation. Furthermore, ground-based systems provide surface or near-surface measurements while balloon and airborne platforms facilitate viewing processes such as precipitation, cloud systems, surface vegetation, water or ice from a high-altitude vantage point, and with high spatial and/or spectral resolution. Major field campaigns supported by the Division frequently need observations at multiple levels and thus require simultaneous ground, air, and space observations.

9.1 Instruments

Technological advances are often needed to make new measurements. These measurements often require improved spatial, spectral, and temporal characteristics, or require the instruments to operate in a new environment or vantage point.

Technology improvements occur in the instrument area (new or better detectors, lasers, radar components, etc.), in the spacecraft area (large apertures, deployable structures, low power rad-hard electronics, small sensorcraft, station keeping/pointing/formation flying activities…), in the information technology arena (data compression, high speed downlink, redeployment), and other areas.

The need for improvements in temporal coverage has driven many of the advanced observing scenarios to take advantage of new vantage points such as Geosynchronous/Geostationary Earth Orbit (GEO) and L1/L2 orbits. These new vantage points will require additional improvements in the Signal to Noise Ratio (SNR) of our detectors, the size of our apertures, greater on-board processing capability, and more efficient and more powerful active measurement components (such as lasers) than traditional vantage point locations.

A substantial component of our efforts is to develop in-situ and suborbital (aircraft, balloon and UAV/UAS) versions of the instruments in order to demonstrate the usefulness of the measurement and the maturity of the technology. This substantially reduces the risk to NASA in introducing new measurements and technology into future observations.

Funding for technology development activities is usually obtained through a competitive process. For low Technology Readiness Level (TRL) activities, funding may come from either broadly competed programs, directly from existing instrument programs, or from programs funded internally by GSFC, such as the IRAD funds. As technology progresses beyond the low TRL levels, scientists, and engineers may compete for potential funding from one of the Mid-TRL technology programs available via the ROSES solicitation or through GSFC's IRAD. If a technology is mature enough that it might make a substantial difference toward a winning proposal, it might also be eligible for B&P funding.

Table 1 in Chapter 5 shows the current group of ESD missions and instruments being developed.

Below we summarize instrument activities:

Lidars

Laser- and Lidar-based instruments are an essential part of future Earth observations. MOLA on NASA's Mars Global Surveyor, the Geoscience Laser Altimeter System (GLAS) on ICESat, and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) laser on CALIPSO have clearly demonstrated the tremendous advancement in measurements that can be provided with lidar-based space instruments. The NRC Decadal Survey has identified a number of essential measurements and missions (ICESat-II, DESDynI, ASCENDS, and LIST) that are expected to be accomplished by lidar-based instruments.

We are currently working on the design and development of lidars for topographic information, cloud and aerosol height, trace gas concentrations, and wind speed and direction measurements. We are also addressing the technology challenges associated with the limited laser power and diode lifetime of these types of instruments.

The next five years will see improved capabilities in resolution and vastly improved transportability, including application to UAS platforms.

Microwave Remote Sensing

The capabilities of microwave instruments such as TMI, the ER-2 Doppler radar (EDOP), the NASA Polarization radar (N-POL), and radiometers such as the Airborne Earth Sciences Microwave Imaging Radiometer (AESMIR), the Conically Scanning Millimeter-wave Imaging Radiometer (CoSMIR), and the Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR) have had profound effects on Earth Science measurements. Through the development and application of these instruments we have fundamentally changed our ability to observe and understand important aspects of the Earth system, including ocean salinity, precipitation, soil moisture, cold land processes, sea ice, and ocean wind measurements. Present and proposed future missions are based on these developments. Our ongoing support of future space missions, including Aquarius, GPM, and SMAP requires planning for anticipated retirements in the area of precipitation radars operating in space, and on aircraft and the ground. Our present observational capabilities include innovative scanning aircraft microwave radiometers operating through the 1 – 1000 GHz spectrum, and transportable radars (EDOP, N-POL), scatterometers and radiometers. The last five years have seen significant advances in these instruments, including digital beam forming, synthetic aperture radiometry, multiple frequency/polarization radars, SAR and interferometric radars, etc.—that greatly extend the capabilities of these systems. Additionally, there is a continued move to smaller and more flexible airborne platforms, including UASs. Our remote sensing measurements will continue to be buttressed by our focused in-situ sensing program, with its innovative UAS program and autonomous ocean-sensing systems. The Division's instruments are available on a cost-reimbursed facility basis in support of NASA scientific research, and have been used by our sister agencies, including NOAA, DoD, and USGS, as well as by academia.

Visible/UV and Near IR

Historically, the ESD has developed sensors in the UV-visible range, such as for the SBUV and TOMS instruments and Solar and Heliospheric Observatory (SOHO)/Coronal Diagnostic Spectrometer (CDS). However, new measurements from Low Earth Orbit (LEO), GEO, and the Libration point require better spatial and spectral observation and drive the need for better and larger detector systems. New technology developments include UV-visible polarimeters, micro-bolometer and Quantum Well Infrared Photodectors (QWIPS) sensors. Large-format, fast readout detectors from the visible to the extreme ultraviolet (EUV) are central to remote imaging and spectroscopy of the solar atmosphere. The Division has extensive experience with EUV spectrographs and detectors and has proposed spectrograph concepts for an L-1 Earth-Sun mission.

9.2 Improving the Instrument and Mission Development Process

With implementation of FCA and fall-off of support from the EOS missions, the ESD is under pressure to develop and win more instrument and mission proposals. The current process starts with an open call for new mission concepts. These concepts are reviewed by the New Business Review Panel (NBRP) which is chaired by the Chief Scientist. Positively reviewed concepts are funded using B&P allocated resources to strengthen the concept through Integrated Mission Design runs, for example. Progress is periodically re-reviewed by the NBRP, and a mission concept may be deselected if cost is too high (concept is too expensive for the cap) or progress is insufficient.

Recently, our Center Director has re-invigorated the proposal process at Goddard, with the goal of becoming more competitive. ESD will also move strongly to better support proposals at every step of their development and improve the win rate for instrument mission concepts. ESD will establish a permanent New Business Office (NBO) at the Division level. The responsibility of this office would be to proactively connect research activities with proposal opportunities both within and external to Goddard, to track progress on major proposal activity, to provide advice for proposers, and help proposers obtain resources. An opportunities review group that would include Laboratory Heads would meet regularly (biweekly) to provide information and oversight for the NBO.

9.3 New Platforms and Vantage Points

NASA is always seeking to push the envelope of technology and observations. This section discusses the potential opportunities of using new airborne platforms and new space vantage points to make observations.

9.3.1 Unmanned Aircraft Systems

Airborne instruments and observations have always played an essential role in NASA Earth Science investigations. Aircraft missions give the opportunity to develop and demonstrate new instruments and measurements much less expensively than a space mission. This substantially reduces NASA's risk in introducing new measurements and technology into future observations. Aircraft campaigns provide an essential role in calibration and validation of satellite measurements and are key components of any satellite mission.

Unmanned Aircraft System (UAS) provide a new observational capability that is complementary to current and future satellite missions. Currently, there is a significant observation gap between the high resolution capabilities of aircraft measurements, which are limited in spatial and temporal coverage, and satellite observations, which provide a global view, but often without adequate vertical and horizontal measurement resolution necessary to discern important fine scale features. A high-altitude and long-endurance UAS fills this critical observation gap and expands the observational domain with high-resolution data combined with near-global coverage. UASs, developed for military reconnaissance, have large payload capacity, long duration, and high altitude capabilities. Operational UAS flights could impact a broad range of scientific applications, including synoptic weather systems, hurricanes, air quality, stratospheric ozone, ozone depleting substances, greenhouse gases, ice sheets, forest fires, droughts, and storm damage, as well as satellite validation. Additional flights could be allocated for research tasks, including targeted flights with payloads for specific science questions, satellite instrument development, and support of U.S. Government science and applications missions.

A UAS program would become a new and vital component of the emerging Global Earth Observation System of Systems (GEOSS) 10-year implementation plan, which is now supported by over 60 countries around the world. In addition, a UAS program would be similar in cost to a modest cost five-year satellite mission, but the UAS effort would be ongoing and would address a broader range of high-priority science missions, whose societal benefits would greatly improve the quality of life on our planet. GSFC ESD scientists have a number of aircraft instruments developed for the NASA ER-2 that are being modified for use on UASs, along with instruments that are being specifically developed for UASs.

In 2010, the Aura Project will prototype the use of UASs (the NASA Global Hawk) in validation. This Global Hawk Pacific (GloPac) mission will fly a mix of remote sensing and in situ instruments for sampling stratospheric air and tropospheric air pollution, while providing validation observations for the A-train satellites. In addition, the Hurricane Science Research Program is currently planning a field campaign — Genesis and Rapid Intensification Processes (GRIP) for 2010 that will focus on hurricane genesis and intensification in the western Atlantic basin. GRIP will utilize the GSFC HIWRAP instrument.   GSFC is now planning a series of missions on the NASA Global Hawk as part of the Venture Class of science missions.

9.3.2 Geostationary Orbit

Geostationary orbit has long been exploited for weather monitoring, but it is underused with regard to the EOS class multispectral sensors developed for LEO. There are some distinct advantages to the geostationary orbit. Sensors in geostationary orbit can make high time resolution measurements, e.g. every 15 minutes over the same spot (Sun synchronous low Earth orbit satellites can make two measurements per day). GEO allows good monitoring of rapidly changing conditions such as occur during severe weather outbreaks and diurnal pollution episodes. Since GEO is 60 times further from the Earth than a typical LEO, larger apertures for sensors are needed to achieve the same ground resolution as from LEO. On the other hand, GEO satellites can stare at the same spot for a longer period and thus achieve equivalent or better signal-to-noise that a low Earth orbit sensor can achieve. GEO is naturally situated to observe the high-energy particles and field fluctuations in the middle of the Earth's magnetosphere. GEO is also a vantage point for continuously monitoring solar EUV and X-ray activity. GEO sensors and satellites are technically challenging because they need to be compact, power conserving, light-weight, and long-lived.

NOAA is now procuring the next generation of geostationary operational environmental satellites (GOES-R) to launch in 2015. The entire NOAA GOES-R activity (program office, flight project, and ground system project) is hosted at Goddard and jointly staffed by NASA and NOAA. Significant advancements in GOES-R instrumentation will include an EOS-class imager and a lightning mapper. The NRC has also called for a demonstration of hyperspectral sounding from GEO, and there is space for such an instrument on the GOES-R platforms, awaiting funding. The Division already provides NOAA with a Project Scientist for the existing geostationary satellites and for the GOES-R effort. In addition to the GOES-R activity, the Division has written proposals to either provide instruments for GOES-R or develop complete geostationary science packages looking, for example, at tropospheric air-quality.

In addition to Earth science objectives, the geostationary orbit also offers clear advantages to space science research. For example, the proximity to Earth of GEO permits transmitting the high data rates provided by the measurements of the Solar Dynamics Observatory with substantial ESD involvement.

Over the next five years, we expect that opportunities will appear for advanced GEO instruments and science data products to monitor the Sun-Earth environment.

9.3.3 Venture Class Concepts

In addition to the Earth Science Systematic Measurements missions identified in the NRC Decadal Survey and listed in Table 1 of Chapter 5, the Earth Science Line of Business is developing a series of Venture Class instrument and mission concepts as part of NASA's Earth Science Directorate's Earth Venture (EV) Program.

The EV Program was created in 2009 as a new element within the ESSP Program. EV consists of a series of regularly solicited, competitively selected Earth Science investigations. The EV program intends to solicit proposals on an on-going basis with current plans for a solicitation every two years that will include suborbital science investigations, instruments of opportunity and stand alone space missions. EV missions are intended to be innovative, integrated, and hypothesis or scientific question-driven approaches to Earth system science, involving temporally sustained data acquisition.

ESD submitted a number of proposals in response to the first EV solicitation for suborbital investigations that was released in July 2009. The ESD proposals addressed a variety of science with applications to a number of national needs. Specific areas of proposed investigations included cryosphere science (permafrost change), biosphere science (ecosystem structure), and atmospheric chemistry and dynamics (hurricane research and monitoring).

The Division, in collaboration with other NASA Centers and the community, continues to actively engage in the development of instrument and mission concepts for future EV solicitations. It is anticipated that the next solicitation will be for standalone space mission concepts on the order of $150M per mission.

9.3.4 International Space Station Utilization

The NASA HQ Science Mission Directorate, in collaboration with the NASA HQ Space Operations Mission Directorate and Exploration Systems Mission Directorate, issued a solicitation for proposals to use the station's resources and accommodations in support of future NASA missions. Candidate concepts were solicited from each NASA Center for projects that can be implemented on the International Space Station (ISS) within the next 36 months.

ESD identified and submitted numerous instrument concepts for this opportunity including lidar for aerosol and carbon measurement, hyperspectral imaging for carbon monitoring and interferometry for greenhouse gas measurement. GSFC and ESD will continue to develop concepts for ISS Utilization that take advantage of our unique instrument development and science capabilities.

10. Applications

The importance of the transition from research to applications has been emphasized in the NRC Decadal Survey. The Division intends to increase its involvement in the utilization of the progress that is being made in Earth system science for the benefit of society. SMAP, Aquarius, Glory, and missions recommended by the NRC Decadal Survey will offer opportunities to improve our air quality, agricultural efficiency, ecological forecasting, public health, and other application areas by providing additional data and products.

We plan to continue our investments in the areas identified in Chapter 5, Table 2, specifically:

Water Management
The current emphases of our Water Management activities are in the areas of: (1) stream flow and flood forecasting; (2) water supply and irrigation; and (3) drought monitoring and seasonal predictions. We are working to extend to the areas of water quality and water resources. Recently, NASA, working with the U.S. Agency for International Development (USAID) and the World Bank, has begun to assess the use of NASA satellite and modeling information to assist the Arab Water Council toward improved water management in the Middle East and North Africa (MENA) region. We are assessing the value of using the NASA Land Information System with satellite products (e.g., MODIS land cover and TRMM precipitation) as a regional water data platform to assist with the region's acute issues of water scarcity and quality.

Disaster Management
There will be significant attention given to expanding the Disaster Management portfolio to give greater emphasis on earthquakes, drought, floods, landslides, and wildfires.

Air Quality
The Air Quality effort has grown beyond its original focus of determining air quality indices using MODIS Aerosol Optical Depth versus PM-2.5 correlation data. We have initiated use of Aura OMI NO_2 and SO_2 data in building updated and more comprehensive inventories of reactive nitrogen and sulfur compound emitters and in correlating OMI NO_2 (i.e., ozone precursor) with the atmospheric lightning data obtained from TRMM lightning mapper. We are also infusing these products in the Environmental Protection Agency (EPA)'s CMAQ model to produce improved air quality assessments and forecasts.

Public Health
We currently are conducting projects within the Public Health theme in the area of epidemiologic surveillance and risk mapping of vector-borne infectious diseases e.g., Ebola, Malaria and Avian Influenza. Future efforts under this theme will be to continue and mature our work on the Avian Influenza and expand it to include environmental health risks due to trace gasses and aerosols.

Agriculture
Our current work under the Agriculture theme is to provide remote sensing products to improve global crop yield assessments and forecasts. We also have developed an invasive plant species forecasting system. In the future, we plan to put additional emphasis on partnerships that can use NASA Earth science products to improve agriculture practices to mitigate sediment nutrient loadings of water bodies. Additionally, we will examine opportunities to provide products to the growing field of carbon management.

Ecosystems Forecasting
Under the Ecosystem Forecasting theme, we will investigate and explore the applicability of research products for protecting the endangered species due to climate and land cover/use changes. This will again require establishing partnerships with a broad range of end users.

Weather

We are involved in both space and terrestrial Weather related applications. Primary activities are utilizing precipitation products for agriculture yield forecast and solar wind impact on U.S. high voltage electrical grid for the electric power industry. We plan to expand these areas to include space weather forecasting for aviation and improving the availability of accurate weather information to support the transportation and global mobility of people and material.

We are planning to expand our participation in international programs such as SERVIR and TIGER. SERVIR is a multi-center crosscutting activity dealing with East Africa and other regions of the African continent. There is a greater interest by the U.S. Department of State and other world organizations to deal with Africa's multiple societal issues including droughts, floods, malaria, rift valley fever, fires and aerosols, ecosystem changes, and water resources, including the health of Lake Victoria and Chad basins. We have been closely working with the European Space Agency and Canadian Space Agency via their TIGER initiative. This initiative addresses water resources and capacity building in the continent of Africa. Our involvement in this initiative is to facilitate sharing of each other's water related data and research results and to further the objectives of the SERVIR project.

Further information on the Division's application activities is contained in Appendix A, Table A.3.

11. Education and Public Outreach

The management of outreach programs and activities must be well integrated, strategic, and sustainable, and must coordinate activities between GSFC, HQ, and other NASA centers. Clearly, it must also be firmly grounded on the most relevant science. Organizing all the ideas and approaches to education and public outreach has always been a challenge as many of them began as *ad hoc* initiatives. Many of our EPO initiatives were born out of new flight missions, which are by their nature, transitory (approximately 3-6 year prime missions). EPO implementation plans submitted for the 2009 NASA Earth Science Senior Review by EPO leads for Terra, Aqua, Aura, and ICESat (all ESD based) emphasize better cross-mission coordination and collaboration.

Over the next five years, the Division seeks improved delivery of its outreach to the public, public media, the research community, policy makers, and formal and informal educators. Under the leadership of the Division's EPO Coordinator who reports to the Director of the ESD, the priority for the new science stories and EPO content/materials will be established for our target audiences. He/she is an Earth scientist who will serve as a science communicator, and help formulate ideas for education and outreach and suggests implementation strategies to the ESD Director. The Coordinator works closely with EPO staff within the Division, including the Scientific Visualization Studio and mission-based education/outreach staff, and has regular interaction with the GSFC and HQ Office of Public Affairs and Education Offices, to help promote a clear, consistent EPO theme. The ESD Coordinator will also work within the newly-formed Earth Science Education and Public Outreach Forum (SEPOF), which is one of four NASA-funded forums to better coordinate and centralize NASA's EPO efforts. The ESD will work closely with HQ to establish performance assessment metrics.

The Coordinator will work closely with existing GSFC EPO Working Groups to identify or make available resources needed for special EPO projects. These working groups were established to encourage coordination in the development and evaluation of our programs and products. While they have evolved over the years, the current groups are listed below:

- Science Communications (aiming at assisting scientists interested in EPO)
- Professional Development (for the EPO Community in areas such as evaluation tools and techniques)
- Formal Education
- Informal Education

All four of the Working Groups work closely with and include representation from the GSFC Education Office and individual Earth Science missions. Details on the formal/informal working groups and the working group objectives follow:

Formal Education: Our goal is to target our communications toward curriculum decision makers at the state and district levels, and infuse Earth science imagery and information into the science, math, and geography curriculums at all grade levels (kindergarten through graduate). We will increasingly promote the complementary use of real NASA remote sensing data along with models in inquiry-based lessons designed to instruct about NASA Earth sciences content.

Informal Education: Our efforts focus on building, sustaining and expanding partnerships and collaborative efforts with informal education institutions and professional groups, and with professional communications and science advocacy organizations. We target groups that demonstrate extensive and well-proven effectiveness with the public (for example major science centers and museums, and agency partners such as the National Park Service and the U.S. Fish and Wildlife Service). Our main delivery mechanism is through professional development of informal educators, via workshops and presentations at professional conferences. We also partner with institutions to create new venues for showcasing ESD data and science content (for example, Science on a Sphere programs and programming for the UniView Dome and Magic Planet).

An objective of the working groups is to clearly identify the target audience, and to quantify their current perceptions of NASA's Earth science programs. In parallel, the ESD will work with NASA HQ and the Earth SEPOF to establish the proper communications channels in reaching out to this segment of the public.

The EPO Working Groups exist to improve communications and to ensure that our programs and products are inclusive, effective, and efficient. The EPO efforts need to focus on mission measurements and science. The overarching strategy must combine the publicizing of new results along with integrating these results into the mission of the Division. To be successful, the working groups must operate less in terms of promoting individual flight missions and/or laboratories, and more in terms of the interests, cognitive, and technological capacities of their target audiences. While the working groups maintain autonomy, they work cooperatively when such needs arise. Such a decentralized model can work well by delegating and distributing the burden of work and cost while bypassing decision-making bottlenecks that are inherent in more traditional top-down management hierarchies.

We will emphasize the Web as a primary medium of choice for distributing information because research shows it has become the medium of choice by all of our target audiences when seeking scientific information for their jobs, for schoolwork, or for just keeping up with what's new. Moreover, the Web is a robust medium in that it allows easy translation to other media, including print, television, radio, and live presentations. In short, the Web gives us a focal point for better internal cooperation as well as the means to better serve our audiences.

ESD EPO programs and products will emphasize information assets that are unique to the ESD: (1) our new science results, (2) our measurement capabilities and data products, and (3) our data integration and analysis tools, and predictive models.

Part III

Appendices

Appendix A. Missions and Application Activities

Table A.1. Missions in Development

Mission Name	Launch Date	Mission Description	Center Lead
Aquarius	May 2010	To collect sea surface salinity (SSS) data over the global oceans	JPL
Glory	Oct. 2010	Aerosols measurements; Total Solar Irradiance	GSFC
Landsat Data Continuity Mission (LDCM)	Dec. 2012	To provide continuity for land use/land cover change	GSFC
Global Precipitation Measurement (GPM)	July 2013	Global Water Cycle precipitation measurements	GSFC
NPOESS Preparatory Project (NPP)	2013	To provide continuity in measurements between EOS and NPOESS programs and pre-operational risk reduction	GSFC
Geostationary Operational Environmental Satellites (GOES)		To provide a constant vigil for the atmospheric “triggers” for severe weather conditions	GSFC
Polar Operational Environmental Satellites (POES)		To provide measurement of various parameters for operational use	GSFC

Table A.2. NRC Decadal Survey Recommended NASA Missions

Mission Name	Mission Description	Concept Instruments	Center Lead
Near-Term Launch (2010-2013)			
ICESat-II	Ice sheet height changes for climate change diagnosis	Laser altimeter	GSFC
SMAP	SMAP soil moisture and freeze/thaw for weather and water cycle processes	L-band radar L-band radiometer	JPL
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	L-band InSAR Laser altimeter	JPL/GSFC
CLARREO (NASA portion)	Solar radiation; spectrally resolved forcing and response of the climate system	Absolute, spectrally resolved interferometer	LaRC
Mid-Term Launch (2013-2016)			
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	Backscatter lidar Multiangle polarimeter Doppler radar	GSFC
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	Multifrequency laser	GSFC/LaRC
GEOCAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	Hyperspectral spectrometer	LaRC/GSFC
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	Hyperspectral spectrometer	JPL
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	Ka-band wide swath radar C-band radar	JPL
Long-Term Launch (2016-2020)			
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	Doppler lidar	TBD
GRACE-II	High temporal resolution gravity fields for tracking large scale water movement	Microwave or laser ranging system	TBD
LIST	Land surface topography for landslide hazards and water runoff	Laser altimeter	TBD
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	UV spectrometer IR spectrometer Microwave limb sounder	TBD
SCLP	Snow accumulation for fresh water availability	Ku and X-band radars K and Ka-band radiometers	TBD
PATH	High frequency, all-weather temperature and humidity soundings for weather and forecasting and SST	MW array spectrometer	TBD

Table A.3: Application Activities

App. Theme	Project	NASA & Other Sensors/Sat Used	Partner Utilizing NASA Products	Data and Products Provided	Specific Algorithms or Models Transferred	Potential Societal Benefits
Agriculture	Drought Index for Agriculture Applications	Numerous satellite systems contributing to GMAO seasonal forecasts	- U.S. Drought Monitor and U.S. Drought Outlook (NOAA /NCEP)	- Forecasts of soil moisture for 3 months. - Provided each month	Statistical analysis performed on GMAO seasonal forecasts	Improved delineation of current drought state and a better estimation of future drought
	FEWSNET (Famine Early Warning System Network)	MODIS Landsat NOAA AVHRR TRMM SRTM AMSR-E Meteosat	-USAID -United Nations' World Food Program	-NDVI/mo -Decadal rainfall -Modeled vegetation -Humidity -Precipitable water (3 mo future)	Models predicting biophysical parameters 1, 2 and 3 months in advance	Early Warning of flood and drought in Africa for food security
Air Quality	Dynamic Updating of Emissions to Support Air Quality Forecast and Analysis	Aura/OMI	Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC	Tropospheric NO2 and SO2, Daily	Improved and updated anthropogenic emission inventories	Improved air quality modeling
	Environmental Forecasting Capability	MODIS MISR CALIOP	NOAA NCEP	GOCART global aerosol model	GOCART aerosol model code implementation in the NOAA Global Forecast System	-Improve national weather forecasts -Improve air quality (PM2.5) forecasts
Disaster Mgmt.	Global Floods and Landslides Monitoring and Forecasting	MODIS Landsat AMSR TRMM SRTM AMSU	-International Red Cross -Pacific Disaster Center -SERVIR -USAID	Cross sensor calibrated Precipitation 3B42, flood forecast and flood potential maps (ea. 3 hours)	Global VIC Flood Model	Global Early Warning for Flood and Landslide potential
	SERVIR Africa	MODIS Landsat EO-1 TRMM SRTM AMSR AMSU	-RCMRD Nairobi, Kenya -Disaster Management agencies in Kenya, Tanzania, Uganda, and Ethiopia	- Calibrated Precip 3B42, flood forecast and flood potential maps -NDVI (monthly anomalies)	-VIC Flood Model, -Flood Mapping algorithms	Early Warning for Flood potential and Rift Valley Fever outbreak

Table A.3: Application Activities (continued)

App. Theme	Project	NASA & Other Sensors/Sat Used	Partner Utilizing NASA Products	Data and Products Provided	Specific Algorithms or Models Transferred	Potential Societal Benefits
Ecological Forecasting	Invasive Species Forecasting and Management	MODIS EO-1 SRTM	-U.S. Geological Survey -Bureau of Land Management- -National Park Service	Landscape-scale habitat suitability maps for invasive species	Geostatistical models of resource spatial distributions	Early detection of habitats potentially vulnerable to invasion
	Congo Basin Monitoring using Satellites - CARPE	Landsat MODIS SRTM	USAID / CARPE	-Improve Decadal Forest Change Mapping product 2005); -Corrected & mosaicked Landsat imagery -State of Forest Report	DFCM algorithm to be transferred to the Observatoire Satellital des Forêts d'Afrique Centrale for operational monitoring in Kinshasa	Reduce the rate of forest degradation and loss of biodiversity in the Congo Basin
Public Health	Malaria Modeling & Surveillance	AVHRR MODIS Landsat ASTER TRMM SRTM EO- 1 SIESIP Commercial satellite data	-DoD org. -Local public health org.	-Locations of potential larval habitats -Current and future malaria prevalence -Malaria transmission under various scenarios	-Habitat Identification Model -Prevalence Model -Agent-Based Discrete Event Transmission Model	Reduction in morbidity & mortality due to malaria
	Predicting Zoonotic Hemorrhagic Fever Events	AVHRR MODIS TRMM Meteosat SRTM	-DoD Global Emerging Infections Surveillance and Response System -WHO /FAO	Risk maps of zoonotic hemorrhagic fever monthly and on demand, for Sub-Saharan Africa and Arabian Peninsula	-Spatial and seasonal classification algorithms of endemic regions; -Eco-climatic modeling for risk maps	Early Warning system for Ebola, Rift Valley Fever, and Marburg events

Table A.3: Application Activities (continued)

App. Theme	Project	NASA & Other Sensors/Sat Used	Partner Utilizing NASA Products	Data and Products Provided	Specific Algorithms or Models Transferred	Potential Societal Benefits
Water Resources	Enhanced GRACE Water Storage for Drought Monitors	GRACE TRMM MODIS Landsat	NOAA NCDC; U. Nebraska, Lincoln	Weekly groundwater and soil moisture anomalies	Data assimilating version of Catchment land surface model	Improvement in U.S. and North American Drought Monitor products
	Middle East – North Africa Land Data Assimilation System (Arab LDAS)	GRACE TRMM MODIS Landsat	USAID; Arab Water Council	3-hourly and longer groundwater, soil moisture, irrigation water usage, evaporation, and runoff maps	Land data assimilation system optimized for the MENA region	Cooperation among Arab nations on water resources assessment and planning
Weather	Space Weather Impacts on Energy Sector	LASCO/SOHO MAG/ACE SWEPAM/ACE	-Electric Power Research Institute -North American power utilities	Forecasts of geomag. currents in the North American grid. (i) 1-2 day forecast (ii) 30-60 minute forecast	-Algorithms for optimizing the GIC modeling process. -Incorp. into SUNBURST decision support tool	Power transmission industry to mitigate the potentially catastrophic effects of GIC on the grid(s)
	Advanced Weather Interactive Processing System (AWIPS)	TRMM CloudSat CALIPSO	NOAA	Under Development	Under Development	Severe weather Early Warning

Appendix B. Education and Public Outreach Activities

Below are the education and public outreach activity details mentioned in the main text of this report.

B.1) Education

Formal Education

College Student Programs

The following have been supported by the Division in the past and represent the types of programs the ESD expects to maintain in the future:

- ***Undergraduate Students Summer Program*:** Organized through the University of Maryland, Baltimore County.

- ***Graduate Student Summer Program*:** Consisting of roughly 10 students, this program is organized by the GEST Center of the University of Maryland, Baltimore County.

- ***Research and Discover Summer Internship Program with the University of New Hampshire (UNH):*** The objectives of this program are to recruit outstanding young scientists into research careers in Earth sciences and Earth remote sensing, and to support Earth science graduate students enrolled at UNH through a program of collaborative partnerships with NASA Goddard scientists and UNH faculty.

- ***The NASA Academy*:** Designed to develop space leaders at a number of NASA Centers, this educational program has targeted late undergraduates/early graduate students. This program is managed by the University Programs Office.

Joint Centers Collaborative Support of Graduate Students

The Joint Centers have fostered partnerships with academic institutions wherein the two entities can employ their complementary talents and facilities to enhance Earth and space science research and the education of present and future generations of scientists. A list of the active Joint Centers is shown in the next table:

Partnerships between ESD and the Academic Community

Center for Climate Systems Research, with Columbia University Earth Institute
Center for Earth-Atmospheric Studies (CEAS) with Colorado State University
Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA) with Howard University
Cooperative Institute of Meteorological Satellite Studies (CIMSS) with University of Wisconsin, Madison
Earth System Science Interdisciplinary Center (ESSIC) with University of Maryland, College Park
Goddard Earth Sciences and Technology Center (GEST Center) with University of Maryland, Baltimore County
Joint Center for Earth Science (JCES) with University of New Hampshire
Joint Center for Earth Systems Technology (JCET) with University of Maryland, Baltimore County
Joint Interdisciplinary Earth Science Information Center (JIESIC) with George Mason University
Two cooperative agreements with the Applied Physics and Applied Math Departments of the Columbia University School of Engineering

These partnerships are meant to result in joint research proposals and joint efforts to provide instruction and training. To foster such interactions, coordinated efforts have taken place at the Joint Centers to identify students (as they enter the graduate programs or as they are about to choose their thesis topic) whose interests are shared by a University professor and an ESD scientist. In such cases, ESD pays for the student support for the first year and the University professor and the ESD scientist share the responsibility for supporting the student to the completion of his/her degree. Typically, the ESD scientist becomes a member of the student's thesis committee. The students are encouraged to spend time at GSFC. See the table below for the list of graduate students supported.

Graduate Students Selected at the Joint Centers

Student Name	University	Field	Advisor/Sponsor	Yr. Started / Yr. Finished (Expected)
Toshihisa Matsui	Colorado State University (CSU)	Aerosol effects on the microphysics of clouds	Roger Pielke Sr. (CSU) W.-K. Tao (GSFC)	2002 / Fall 2006
Derek Posselt	Colorado State University (CSU)	Assimilation of satellite-observed cloud properties into GCMs	Graeme Stephens (CSU) Arthur Hou (GSFC)	2003 / Fall 2006
Kevin Mallen	Colorado State University (CSU)	Radar analyses and studies of precipitation systems	Michael Montgomery (CSU) Scott Braun (GSFC)	2004 / (Fall 2008/TBD)
Maike Ahlgrimm	Colorado State University (CSU)	GLAS-derived cloud climatologies	Dave Randall (CSU) Jim Spinhirne/Steve Palm (GSFC)	2005 / Fall 2007
Kelley Wells	Colorado State University (CSU)	Remote sensing of aerosol absorption	Sonja Kiedenweis (CSU) Lorraine Remer (GSFC)	2006 / (Spring 2009)
Nicholas Parazoo	Colorado State University (CSU)	Carbon cycle modeling	Scott Denning (CSU) Randy Kawa/Wei-Kuo Tao (GSFC)	2007 / (Spring 2010)
Nick Guy	Colorado State University (CSU)	Ground based radar data	Stephen Rutledge (CSU) Wei-Kuo Tao (GSFC)	2008 / (Spring 2011)
Shaima L. Nasiri	University of Wisconsin	Satellite-MODIS observed cloud properties	Steve Ackerman (UW) Michael King/Steve Platnick (GSFC)	2002 / Fall 2004
Robert Holz	University of Wisconsin	Spectral properties of clouds and impact of clouds on climate	Steve Ackerman (UW) Matthew McGill (GSFC)	2004 / Fall 2005
Brent Maddox	University of Wisconsin	MODIS and clouds	Steve Ackerman (UW) Steve Platnick (GSFC)	2006 / (Fall 2009)
Chris Danforth	UMCP	Chaos processes in general circulation models/GCMs	David Levermore/Eugenia Kalnay (UMCP) Robert Cahalan (GSFC)	2002 / Winter 2006
Elizabeth Brabson	UMCP		Ragu Murtugudde (UMCP) Siegfried Schubert (GSFC)	2003 / Fall 2008 (M.S.)
Elana Klein Fertig	UMCP	GCM data assimilation	Eugenia Kalnay (UMCP) Ricardo Todling (GSFC) Ron Gelaro (GSFC)	2003 / Fall 2007
Wilfred Schroeder	UMCP	Fire characterization over large scales using satellite data	Ruth DeFries (UMCP) Jeff Morisette (GSFC)	2004 / Spring 2008
Christopher Blakely	UMCP	Spectral approximations of discrete data defined on a sphere	Ferd Baer (UMCP) Tom Clune (GSFC)	2004 / (Spring 2009)

Graduate Students Selected at the Joint Centers (continued)

Student Name	University	Field	Advisor/Sponsor	Yr. Started / Yr. Finished (Expected)
Hezekiah Carty	UMCP	Interactions between the oceans and the atmosphere as related to TRMM observations	Sumant Nigam (UMCP) Eric A. Smith (GSFC)	2005 / (MS 2006, Ph.D. 2009)
Stephen Penny	UMCP	Innovative numerical methods in geophysical problems	Charles D. Levermore (UMCP) Warren Wiscombe (GSFC)	2005 / (Spring 2009)
Karl Wurster	UMCP	Land use and energy using remote sensing	Ruth DeFries (UMCP) Marc Imhoff (GSFC)	2006 / (Spring 2010)
Felicita Russo	UMBC	Micropulse lidar extinction measurements using Raman Lidar	Ray Hoff (UMBC) David Whiteman (GSFC)	2002 / Summer 2007
Antonia Gambacorta	UMBC	Raman Lidar studies of water vapor, cirrus cloud optical depth, particle size, and ice water content	Ray Hoff (UMBC) David Whiteman (GSFC)	2003 / Winter 2008

Additional Interactions

Interactions with graduate and undergraduate students also take place outside the formal programs outlined above, and are encouraged by all levels of management in the Division. About 50 students spent time in the Earth Sciences Division during the 2009 year. In addition, many members of the ESD staff are part of M.S. and Ph.D. thesis committees, supporting students at universities from across the country. In the past, much of this collaboration has been through the Joint Centers. See the next table for a list of ESD scientists that were thesis advisors.

ESD Scientists that were Thesis Advisors in Academic Year 2009

Scientist		
Alexander Marshak *	Eyal Amitai *	Matthew Rodell * (2)
Benjamin Johnson # *	G. James Collatz # *	Oreste Reale *
Charles Gatebe *	Gerald Heymsfield * (2)	Rolf Reichle * (2)
David Lary #	Jack Xiong *	Scott Braun * (2)
Dorothy Hall #	James Irons *	Steven Platnick *
Dorothy Peteet *	John Moisan *	Thomas Neumann # (2)
Drew Shindell * (3)	Karen Mohr * (3)	Timothy Hall * (2)
Edward Kim * (2)	Kenneth Pickering # (3) * (2)	
Ellsworth Welton # *	Maria Tzortziou # *	

Masters committees * Ph.D. committees

The table below lists courses taught by ESD scientists.

Courses Taught by ESD Scientists in Academic Year 2009

Location	Title of Course	Instructor
Columbia University	Dynamics of Climate, Dept. of Earth and Environmental Sciences	Ronald Miller
Columbia University	Introduction to Atmospheric Chemistry, Dept . of Earth and Environmental Sciences	Drew Shindell
Columbia University	Terrestrial Paleoclimate	Dorothy Peteet
Columbia University	Wetlands and Climate Change	Dorothy Peteet
Summer Colloquium on Data Assimilation *	Land Data Assimilation	Rolf Reichle
University of Maryland, Baltimore County	Atmospheric Physics	Tamas Varnai
University of Maryland, Baltimore County	Atmospheric Physics – Thermodynamics portion	Benjamin Johnson (co-instructor)
University of Maryland, Baltimore County	Computational Physics	David Lary

** Organized by the Joint Center for Satellite Data Assimilation in Stevenson, WA*

Post-Graduate Programs

The Division expects to maintain its support of post-graduate programs, which help foster new, innovative ideas for research. These programs include:

- ***NASA Postdoctoral Program (NPP)***: A program for postdoctoral fellows, run by the Oak Ridge Associated Universities (formerly run by the National Research Council). By carrying out research at NASA Centers, the Fellows contribute directly to the NASA mission while advancing their professional development. This program is funding by the Agency.

- ***GSFC Visiting Fellows Program in the Earth Sciences:*** This program has been organized by the Goddard Earth Sciences and Technology (GEST) Center and has been designed to attract professors on sabbatical leave and researchers at all levels of seniority within the Division. Selected through a competitive process, those chosen are typically pursuing independent research of their choice and have full access to NASA computing facilities and other resources at either the Greenbelt or the New York campus. See the following table for a list of Fellows.

GSFC Visiting Fellows Program in the Earth Sciences

Name	Institution	Research Plan	Relevant ESD Lab
FY 2010			
Wenge Ni-Meister *	Hunter College	Vegetation monitoring	614.4
De-Zheng Sun *	Cooperative Institute for Research in Environmental Science	Water vapor and clouds, ocean-atmosphere coupling, climate system and modeling	613.1
Chien Wang	Massachusetts Institute of Technology	Aerosols and precipitation	613.2
FY 2009			
Johannes Loschnigg	National Academy of Science	Environmental and science policy	610
FY 2008			
Manfredo Tabacniks *	Institute of Physics, University of Sao Paolo, Brazil	Instrumentation and measurements of aerosols	613.2
Ramesh Srivastava ^	University of Chicago	New radar development	613.1
Kurtulus Ozturk	Turkish Meteorological Service	Techniques in rain rate sensing	613.1
Nawo Eguchi *	National Institute for Environmental Studies (NIES), Japan	GEOS-5 assimilation techniques	610.1
Karen Mohr *	State University of New York, Albany, New York	Cloud resolving model development	613.1
Francois-Marie Breon	Laboratoire des sciences du climat et de l'environment	Aerosols	613.2
Jun Wang	University of Nebraska	aerosol data assimilation in numerical models	613.2
FY 2007			
Pieternel Levelt *	KNMI, Holland	Broadening access and use of OMI data	613.3
Alexander Lipatov	University of Calgary	Modeling of magnetospheres/ heliosheaths of planets	610.6/673
Michael Schulz *	Laboratoire des Sciences due Climate et de l'Environment, Gif-sur-Yvette, Franco	AEROCOM	613.2
Tad Anderson *	University of Washington	CALIPSO – A-Train integration of clouds and aerosol data	613.2
Nicholas Meskhidze *	Georgia Institute of Technology	Work on links between air pollution and ocean productivity	613.3
Raimund Muscheler	Lund University, Sweden	Sun-Earth connections	613.2
Qingyuan Zhang	University of New Hampshire	Remote sensing of photochemical active radiation in vegetation and gross primary productivity	614.4
FY 2006			
Martti Hallikainen *	Helsinki University	Polar climate change, specializing in Microradiometry of snow and ice	614.6
Cynthia Randles	Princeton University	Biomass burning aerosols over Africa	613.2
Cuneyt Utku	George Washington University	L-band radiometry of the ocean and soil with application to Aquarius	614.6

* On sabbatical leave ^ Retired – Professor Emeritus

GSFC Visiting Fellows Program in the Earth Sciences (continued)

Name	Institution	Research Plan	Relevant ESD Lab
FY 2005			
Zev Levin *	Tel Aviv University	Cloud-dust interactions	613
David Salstein	Atmos. & Environ. Research Inc.	Interactions of Earth rotation parameters with atmospheric dynamics	690
Toshiihiko Takemura	Research Institute for Applied Mechanics Kyushu University	Simulation of spectral radiation transport model results	613.3/613.2
FY 2004			
Warren Cohen *	Dept. of Agriculture Forest Service	Forest inventory/carbon	690
Carlos Garcia *	Univ. of Rio Grande, Brazil	Ocean color/primary production	614
Virginia Garcia *	Univ. of Rio Grande, Brazil	Ocean color/primary production	614
Marvin Geller *	State University of New York, Stony Brook	Atmosphere dynamics; stratosphere/ mesosphere; climate	611
Maeng-Ki Kim *	Kongju National Univ., South Korea	Global circulation modeling	613
Roger Lang *	George Washington Univ., Washington, DC	Soil moisture measurements	614
Robert Numrich *	Univ. of Minnesota, Minneapolis, MN	Climate model computing	606
Friedman Freund *	San Jose State Univ., San Jose, CA	Crustal Dynamics	690
Susanne Bauer	Lab. Science, Climate & Environ., Paris, France	Climate modeling/chemistry	611
Hyung Rae Kim	Ohio State Univ., Columbus, OH	Terrestrial physics	690
FY 2003			
Nadine Bell	Earth & Planetary Science, Harvard Univ.	Chemical and dynamical processes in the atmosphere	611
William Chameides *	Earth & Atmos. Sci., Georgia Inst. of Technology, Atlanta, GA	Coupling between atmospheric aerosols, climate, and carbon uptake by terrestrial ecosystems (National Academy of Sciences)	611
James A. Coakley *	Oceanic & Atmos. Sci., Oregon State Univ., Corvallis, OR	Cloud and aerosol retrievals to include an ensemble of aerosol-cloud interaction cases	613.2
Harshvardhan *	Earth & Atmos. Sci., Purdue Univ., West Lafayette, IN	Indirect cloud forcing by anthropengenic sulfate (Dept. Chair)	613.2/613.3
Dan Lubin *	Scripps Inst. of Oceanography, Univ. Cal, San Diego, La Jolla, CA	UV radiation at the surface and its effects on near surface biology	613.3
Michael E. Mann *	Environmental Sciences, Univ. of Virginia, Charlottesville, VA	Oceanic dynamical responses to atmospheric forcing of northern hemisphere ocean temperatures over the past 1000 years	611
Jacques Hinderer *	Univ. of Strasburg, Strasburg, France	Gravity measurements to validate/calibrate GRACE, use GRACE data for hydrological studies	697

* On sabbatical leave ^ Retired – Professor Emeritus

GSFC Visiting Fellows Program in the Earth Sciences (continued)

Name	Institution	Research Plan	Relevant ESD Lab
FY 2003 (cont'd)			
Katherine Whaler *	Univ. of Edinburgh, Edinburgh, England	Modeling satellite magnetic data for the Earth and Mars	698
Wookap Choi *	Earth & Environ. Sciences, Seoul National Univ., Seoul, Korea	Stratospheric trace gas distributions, stratosphere-troposphere exchange, stratospheric cooling from CO_2	613.3
Ken Minschwaner *	Geophys. Research Center, New Mexico Institute of Mining and Technology, Socorro, NM	Processes near the tropical tropopause responsible for transfer of mass and humidity from the troposphere to the stratosphere; studies of tropical cirrus cloud systems	613.3/613.2
Peter Colarco	Univ. of Colorado, Boulder, CO	Aerosol radiative properties using models, field and satellite measurements	613
David J. Lary	Chemical Informatics, Univ. of Cambridge, Cambridge, UK	Chemical Data Assimilation, produce a multi-annual analysis of chemical state of the atmosphere from UARS (Royal Society Fellow)	610.1

* On sabbatical leave   ^ Retired – Professor Emeritus

Two-Year Colleges

Integrated Geospatial Education and Technology Training Project (iGETT): The iGETT will help meet workforce demands for geospatial technologists by enabling two-year colleges to expand existing Geographic Information System (GIS) programs to incorporate a wide range of remote sensing applications. The project was funded by the Advanced Technological Education Program, National Science Foundation in 2007, and will continue until 2010.

40 faculty members who currently teach GIS in a wide range of courses at two-year colleges enrolled in the project, one cohort in 2007 and another in 2008. Each group participates for a period of two years. The first year focuses on geospatial training and development of curriculum materials, the second on course enhancement, program development, student recruiting, and community outreach.

The iGETT Web site provides resources for all two-year college GIS instructors who are interested in replicating parts of the project or in using:

- Training materials provided for the iGETT participants.
- Curriculum materials developed by each participant.
- Outreach and marketing strategies implemented at the participating institution.

iGETT is co-led by ESD EPO staff in partnership with the National Council for Geographic Education, Del Mar College in Corpus Christi, Texas, the Environmental Systems Research Institute, and the U.S. Geological Survey Land Remote Sensing Program. (http://igett.delmar.edu/index.html)

Kindergarten to Grade 12 (K-12) Programs

Support of early education programs remains a priority to the Division. The ESD has produced educational materials and lesson plans for grades K-12, thereby contributing to the pipeline that will produce tomorrow's Earth scientists. The Division's scientists routinely present lectures and demonstrations to K-12 schools and youth groups to help develop an early interest in science. They also mentor students, and serve as judges at local science fairs. ESD scientists also mentor a number of high school students through individual initiatives and projects.

Mission-based education and outreach staff collaborate with the GSFC Education Office to deliver workshops for teachers during summer and to make classroom-based presentations. The Prince George's County Owens Science Center is a partner to develop and deliver NASA content on Science on a Sphere at the Visitor Center. Staff also partner with professional societies, colleges, other federal agencies to provide professional development for undergraduate students and people already in the workforce. Finally, our staff also coordinate with the GSFC Education Office to develop and efficiently support new EPO programs with local/state level K-12 school partners (e.g. Howard, Frederick, Queen Anne's, and Anne Arundel Counties in Maryland) as well as international programs.

Following are a few examples of K-12 programs supported:

- **Educational GCM (EdGCM)**

  Global Climate Models (GCMs) are one of the primary tools used today in climate research. Unfortunately, few educators have access to GCMs, which have generally required significant computing facilities and skilled programmers. In collaboration with the National Science Foundation (NSF), NASA GISS has created EdGCM, software that allows teachers and students to run a state-of-the-art climate model on desktop computers. With EdGCM, one can explore the fundamentals of climate science using tools which are identical to those used in major climate research programs. Many simple climate experiments are possible (e.g. How does a changing Sun warm or cool the planet?), but, it is also possible to investigate current events as they are being studied by climate scientists. EdGCM comes with some prepared scenarios – for example for global warming and ice ages – but teachers can also construct their own scenarios to satisfy curricular requirements. EdGCM allows teachers to produce their own instructional materials (text, charts, images) and easily scales for use at levels from middle school to graduate school.

- **Practical Uses of Math And Science (PUMAS)**

  PUMAS is an online journal, a Web-based collection of brief examples aimed at giving K-12 teachers insights into how the math and science they teach are actually used in everyday life. This site was founded and is edited by Ralph Kahn (613.2). The examples are written primarily by scientists and engineers, and are available to teachers, students, and other interested parties via the PUMAS Web site (http://pumas.nasa.gov/). Scientists contribute their expertise by writing the examples, which may be activities, anecdotes, descriptions of "neat ideas," formal exercises, puzzles, or demonstrations. These examples are widely used by pre-college teachers around the world to enrich their presentation of topics in math and science. PUMAS offers researchers a way to make a substantial contribution to pre-college education with a relatively small investment of time and effort, and at the same time, to get a peer-reviewed science education journal article published on the Web. The National Science Teachers' Association recognized PUMAS by selecting it as a *SciLinks* site, and the National Council of Teachers of Mathematics has honored PUMAS with their *Illuminations* award. Both awards emphasize the continuing use of PUMAS by teachers, a practical sort of recognition appropriate to the site itself.

Informal Education

- **Earth to Sky**

Earth to Sky is an ongoing and expanding partnership between NASA, the National Park Service (NPS), and the U.S. Fish and Wildlife Service (FWS), that enables informal educators to access and use relevant NASA science, data, and educational products in their work. Earth to Sky has produced a series of professional development workshops for informal educators, funded by NASA with in-kind contributions from LDCM, NPS, and FWS, most recently focusing on NASA's contributions to Climate Change science. Week-long workshops during which participants develop action plans are followed by a series of distance learning events to provide further science content and help establish a community of practice.

As of March 2009, 90 participants have received training. Approximately half of these participants are also conducting training of other informal educators. As a direct result of Earth to Sky, thousands of school children and hundreds of thousands to millions of National Park visitors are receiving information on NASA’s contribution to our understanding of Earth and Space. One example is a Park brochure on Global Climate Change, featuring Landsat imagery. Over 400,000 of these have been printed and distributed to visitors in parks across the nation. Results indicate that through exhibits, handouts, public programming and a series of podcasts, the participants have reached over 2.5 million people with climate change science they learned at the workshop.

The partnership will conduct another workshop in 2009/2010, and develop a course on interpreting climate change for use at the National Conservation Training Center in 2011 and following years. A longitudinal evaluation effort aims to demonstrate the degree to which NASA content is used effectively in informal education settings in Parks and Refuges, and the extent to which a community of practice is established. Earth to Sky is co-led by ESD EPO staff in partnership with NPS, U.S. FWS, and University of California, Berkeley.

B.2) Public Outreach

- **Earth Observatory**

The Earth Observatory (http://earthobservatory.nasa.gov/) is an Earth science website that publishes NASA satellite imagery and scientific information about climate and environmental change (including natural hazards) and the use of space-based sensors for Earth science research and applications. There are more than 56,000 subscribers to its weekly newsletter, and the site receives more than 740,000 unique visitors each month. The primary target audience is the "science attentive" public although additional content targets other audiences, including teachers, students, scientists, and public media. The site has won five Webby Awards in the "Science" and "Education" categories, as well as endorsements by Scientific American, Popular Science, TERC (an education research and development organization), the National Science Teachers Association, and many other organizations. Its imagery and visualizations have recently been featured in National Geographic Magazine, CNN, The Guardian (UK), and many other mass media outlets. The site is funded by the EOS Project Science Office.

- **NASA Earth Observations (NEO)**

  NEO (http://neo.sci.gsfc.nasa.gov/) is a Web-based repository of imagery produced from global Earth science data sets. The target audiences for NEO are science centers, museums, formal and informal educators, science communicators, and citizen scientists -- communities that desire high resolution imagery based on Earth science data, but may not possess the expertise to acquire and manipulate the source data to produce imagery themselves. NEO consists of a Web-based browse interface, Web services, and an ftp service to provide for a wide range of user access points. NEO contains over 50 data sets, many in daily, weekly, and monthly composites, and serves 50-100 GB of imagery monthly. The system is funded by the EOS Project Science Office.

- **Visible Earth**

  Visible Earth (http://visibleearth.nasa.gov/) is a Web-based repository of Earth science-related images, animations, and data visualizations from the Earth Observatory and other partners. The site currently holds about 21,000 records and all assets are stored at multiple resolutions. Since all of Visible Earth's assets are extensively indexed, the site lends itself particularly well to content syndication for NASA's communications partners (i.e., museums, formal education lesson developers, the mass media, etc.). Visible Earth receives an average of 200,000 unique visitors per month and serves approximately 850 GB in monthly image requests. The EOS Project Science Office funds this site.

- **Climate Change Information Resource, New York Metropolitan Region (CCIR-NY)**

  The CCIR-NY is an information resource for educators, policymakers, and the general public on the impacts of climate change and variability in the tri-state New York metropolitan area. This Web site provides scientific answers to basic questions about climate change, and how changes might impact New York City. While the site is specifically focused on the Big Apple, some lessons learned here apply to other urban areas. NASA provided the science used to answer basic and specific questions regarding climate change in the New York Metropolitan region. The site includes a series of questions relating to climate change and then answers them in a way accessible to a wide-ranging audience. It was developed under a grant from NOAA to the Center for International Earth Science Information Network, Columbia University, with the collaboration of NASA GISS and Hunter College. (http://ccir.ciesin.columbia.edu/nyc/)

- **Printed Material**

  The EOS Project Science Office produces a wide range of printed material about NASA-wide and GSFC ESD research programs and satellite missions. Specifically, they produce brochures, lithographs, posters, and fact sheets, as well as CDs and DVDs, about Earth science topics and EOS satellites. The EOS Project Science Office funds most of these publications.

- **Conference Support and Organization**

  The EOS Project Office also provides funding for general conference support and organization of NASA presence at numerous national and international scientific and educational conferences [e.g. American Geophysical Union (AGU), American Association for the Advancement of Science (AAAS), National Science Teachers Association (NSTA), American Meteorological Society (AMS), etc.]. As an example, the team played a leading role in organizing the NASA Science Exhibition for the 2009 AGU Fall Meeting in San Francisco, California. Over 16,000 registered attendees gathered in San Francisco for the 2009 Fall AGU Meeting. NASA Earth science showcased NASA satellite data on a new 3' diameter dynamic planet exhibit; booth presentations brought large crowds to multiple sessions spread out over three days; hosted the Ribbon Cutting Ceremony commemorating the opening of NASA's new exhibit by Director of NASA HQ Earth Science Division, Dr. Michael Freilich, and the President of AGU, Dr. Timothy Grove. Finally, the team organized the celebration for the Terra Mission as it celebrated 10 years of accomplishments.

- **Public Media**

  The ESD has adopted a two-pronged approach to communications with the public media. Our primary emphasis is on providing press releases and imagery to the NASA Public Affairs Office (PAO) through the efforts of the Earth Science News and Information Team. In an effort to proactively mine new story ideas, for the past five years, this team has been identifying and developing press releases for PAO. The team reached an all-time high in productivity over the last year and has had many of their stories play in major television and print media outlets. Our secondary emphasis has been to enable "direct to information consumer" communications via our Web sites and the NASA Portal.

- **Data Visualizations**

  There are three outstanding data visualizations teams supported within the ESD – the Scientific Visualizations Studio (SVS), the Visualizations Analysis Laboratory (VAL), and the Visual and Technical Arts Lab (VITAL). All of these teams produce superior quality images, animations, and data visualizations in support of a wide range of the ESD's communications and science activities, including NASA Public Affairs press releases, live presentations, various print publications, television, and video documentaries, etc.

- **Science on a Sphere**

Science on a Sphere, originally developed by NOAA to enhance outreach, is a system which uses high-speed computers, video projectors, and advanced imaging techniques to project images onto a sphere to create the illusion of a planet, the Sun, a moon, or any other celestial body in space. Science on a Sphere is intended to help communicate science to the public, foster science education, and aid scientific visualization by providing a unique and engaging way of looking at the Earth in its "native format" rather than as a distorted flat representation. The latest in space-based Earth observations from imagery and/or data acquired by NASA's many Earth observing satellites will be processed and formatted for display on the Sphere. There is currently a Science on a Sphere in the GSFC Visitors Center. The Science on a Sphere team recently traveled to Copenhagen, Denmark, to provide outreach and science support as an important component of the U.S. presence at the 2009 United Nations Climate Change Conference (COP15).

- **Dynamic Planet**

  The Dynamic Planet provides the content and software interface to Global Imagination's Magic Planet digital video globe, allowing users to view and explore dynamic digital images of the Earth, other planets, and space. The ESD uses two Dynamic Planet configurations, a 24" diameter and a new 48" diameter "high-definition" globe, each with a NASA Science touch screen interface designed to allow users the opportunity explore the changing planet. Dynamic Planet highlights include its vital role in the United Nations Educational, Scientific, and Cultural Organization's (UNESCO) 34th General Conference (October 2007, Paris, France) and in the opening ceremonies of UNESCO's International Year of Planet Earth (February 2008, Paris, France)

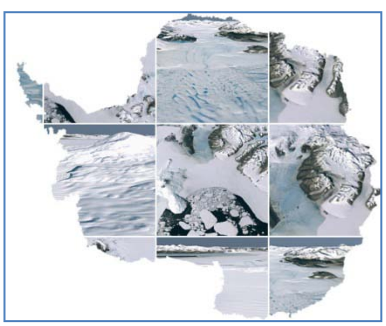
- **ICESat Exhibit**

  The ICESat Mission focuses on the collection of elevation data from ice sheets, sea ice, vegetation, aerosols, and clouds. In order for the visiting public, students, and educators to become better familiar with this vital NASA mission, there are now three new ICESat exhibits in place and plans for more in the near future. Viewers will come away with a feeling of knowing just how important this research is in understanding our planet and how the results and data returned from ICESat does, and will, aid us in predicting future trends in sea-level change and overall climate literacy.

- **The Electronic Theatre**

  The Electronic Theatre produces interactive, high-definition live presentations about Earth system science and NASA's remote sensing missions as an adjunct activity that leverages off the resources produced by the ESD's visualizations teams. This activity reaches thousands of live audience members each year.

- **The Landsat Image Mosaic of Antarctica (LIMA) Education Project**

  The NASA LIMA Education Project (http://lima.nasa.gov) is housed at the NASA Goddard Space Flight Center's Hydrospheric and Biospheric Sciences Laboratory. In the format of an interactive website, it is designed as part of the International Polar Year to educate people about Antarctica through LIMA images, activities, visualizations, scientist interviews, and NASA's role in Antarctic research. Through the website's materials and particularly the "Antarctic Mysteries" section, students and educators can explore the continent.

- **Continuing Mission EPO Activities via Senior Review funding**

  Previous Senior Review proposals have included separate budgets for EPO activities. For the most recent Senior Review funding period (FY08-09), activities have included Earth & Sky Podcasts, GSFC-produced Vodcasts, content for museum distribution (Space Telescope Science Institute's ViewSpace program), and a variety of other efforts.

Appendix C. Hiring Strategies

This appendix contains two tables. The first table identifies the hiring priorities for the near-term. The second table includes the longer-term hiring priorities.

Near-term Hiring Priorities

Work Description	Focus Area	Link to Missions in Development and Future Missions	Relation to HQ Priorities
Senior atmospheric scientist with international reputation in the area of atmospheric composition (ST position)	Atmospheric Composition	ACE, GCAM, Venture Class missions	Atmospheric Composition
Atmospheric Model physics development	Weather and short-term climate	CloudSAT, CALIPSO, GPM, PATH, GeoCAPE, ACE	Weather Climate Variability and Change
Integrated System Modeling Lead	Weather and short-term climate	GPM, SMAP, SWOT, ACE, ASCENDS, GEOCAPE, ICESat-2	Climate Variability and Change Water and Energy Cycle Atmospheric Composition
Scientist/engineer/Information Technologist focusing on data fusion/ provenance/ visualization			
Chief of Global Change Data Center			
Earth scientist with expertise in climate impact applications, hydroclimate assessments, and regional climate model experiments	Climate modeling and analysis	Many satellites that reveal regional climate change	Climate Variability and Change
Radar instrument scientist	Aerosols, atmospheric water cycle	ACE, GPM	Climate Variability and Change, water and energy cycle
Precipitation and remote sensing expert	Atmospheric Water Cycle	GPM	Water and Energy Cycle
Aerosol-cloud-rainfall interaction	Aerosols, atmospheric water cycle	ACE, GPM	Climate Variability and Change, water and energy cycle
Precipitation studies	Atmospheric Water Cycle; Weather and short-term climate	GPM	Atmospheric Composition Water and Energy Cycle Weather
Aerosol-climate interaction	Aerosols; climate modeling and analysis; instrumentation	ACE, GPM, Glory	Climate Variability and Change; Water and Energy Cycle
Aerosol satellite studies, comparing 4-D assimilated data with observations	Atmospheric Composition, Climate	ACE	Atmospheric Composition Climate Variability and Change Water and Energy Cycle Weather

Near-term Hiring Priorities (cont'd)

Work Description	Focus Area	Link to Missions in Development and Future Missions	Relation to HQ Priorities
Satellite chemistry algorithms and calibration	Atmospheric Composition	GEOCAPE, GCAM	Atmospheric Composition
Atmospheric composition studies (junior position)	Atmospheric Composition	ACE, GCAM, Venture Class missions	Atmospheric Composition
Sea ice scientist	Polar climate change	AMSR-E, SMAP, ICESat-2, GCOM-W, NPOESS	Climate Variability and Change
Ocean color	Oceanography	ACE/GEOCAPE/VIIRS; Decadal Survey	Climate Variability and Change; Water and Energy Cycle
Terrestrial water storage data assimilation and analysis expert	Terrestrial Water Cycle	LDCM; NPP; VIIRS + GRACE-2	Terrestrial hydrology; water and energy cycle; water resources applications
Carbon cycle and ecosystems remote sensing algorithm expert	Carbon Cycle and Ecosystems	LDCM, NPP, DESDynI, HyspIRI	Carbon Cycle and Ecosystems relationship with Water and Energy Cycle and Climate Variability and Change
Instrument scientists (2-3)			

Longer-term Hiring Priorities

Work Description	Focus Area	Link to Missions in Development and Future Missions	Relation to HQ Priorities
Ocean data assimilation	Weather and short-term climate	Aquarius, SWOT	Climate Variability and Change Water and Energy Cycle
Ocean circulation model development	Weather and short-term climate		Weather Climate Variability and Change
Climate studies			Climate Variability and Change
Cloud System Modeling	Atmospheric Water Cycle; Weather and short-term climate; Aerosols	ACE, GPM	Water and Energy Cycle
Solar radiation and climate specialist	Climate Variability and Change	NPOESS, NPP	Climate Variability and Change
Ice sheet scientist; experimentalist	Polar climate change	ICEBridge	Climate Variability and Change; Water and Energy Cycle

Longer-term Hiring Priorities (cont'd)

Work Description	Focus Area	Link to Missions in Development and Future Missions	Relation to HQ Priorities
Ice sheet/cryospheric studies	Polar climate change	ICESat-2	Climate Variability and Change; Water and Energy Cycle
Physical oceanography (sea surface temperature and salinity)	Oceanography	Aquarius	Climate Variability and Change; Water and Energy Cycle
Landslide/flood assessment	Terrestrial Water Cycle	TRMM/GPM, LDCM; NPP; VIIRS, SMAP	Precipitation Measurement Missions; Terrestrial hydrology; water and energy cycle; water resources applications
Evapotranspiration/Terrestrial Water Storage	Terrestrial Water Cycle	LDCM; NPP; VIIRS + GRACE-2	Terrestrial hydrology; water and energy cycle; water resources applications
Remote sensing/ecologist (Research Physical Scientist)	Carbon Cycle and Ecosystems	HySpIRI, DESDynI-Lidar, future A/C and space systems	Carbon Cycle and Ecosystems relationship with Water and Energy Cycle and Climate Variability and Change
Ecosystems remote sensing research, land long-term data records and global validation of land science product validation	Carbon Cycle and Ecosystems	EOS Terra, EOS Aqua, NPP and NPOESS and HyspIRI	Terrestrial ecology, land earth system data records, land-use and land cover change though product validation and research in the areas of habitat fragmentation and impact of human activities on species diversity
Radar meteorologist/GPM ground validation scientist	NASA Precipitation Program	TRMM, GPM	Water and Energy Cycle

Appendix D. Project Scientists and Deputy Project Scientists

Project	Project Scientist
Missions in Operation	
Aeronomy of Ice in the Mesosphere (AIM)	Charles Jackman
Aqua	Claire Parkinson Lazaros Oreopoulos (Deputy)
Aura	Anne Douglass Bryan Duncan (Deputy for Science & Validation) Joanna Joiner (Deputy for Instruments, Tech., Outreach)
EOS	Steve Platnick David Starr (Validation Scientist) James Butler (Calibration Scientist)
ICESat	Thorsten Markus Tom Neumann (Deputy)
Landsat 7	Darrel Williams James Irons (Deputy)
New Millennium Program EO-1	Elizabeth Middleton Bruce Cook (Deputy)
SeaWiFS	Chuck McClain Stan Hooker (Deputy)
SORCE	Robert Cahalan
Terra	Marc Imhoff Si-Chee Tsay (Deputy) Robert Wolfe (Deputy for Data)
TRMM	Scott Braun Erich Stocker (Deputy for Data Systems)
Missions in Development	
Aquarius	David Le Vine (Deputy mission PI)
CLARREO	Kurt Thome (Deputy)
DSCOVR	Alexander Marshak (Deputy)
Glory	Michael Mishchenko Eric Wilcox (Deputy)
GOES (Geostationary Operational Environmental Satellite)	Dennis Chesters
GPM (Global Precipitation Measurement)	Arthur Hou Gail Skofronick-Jackson (Deputy) Erich Stocker (Deputy for Data Systems)
LDCM (Landsat Data Continuity Mission)	James Irons Jeffrey Masek (Deputy)
NPOESS Preparatory Project (NPP)	James Gleason James Butler (Deputy for Instruments and Calibration) N. Christina Hsu (Deputy for Algorithms)
SMAP (Soil Moisture Active and Passive)	Peggy O'Neill (Deputy)
ICESat II	Thorsten Markus Thomas Neumann (Deputy) Matthew McGill (Instrument Scientist)

Appendix E. Field Campaigns and Workshops

Field campaigns where scientists in the Division were Principal Investigators in FY2009

Field Campaign	Principal Investigator
Field campaign in Eastern Mediterranean coastal waters	Maria Tzortziou
Field campaign in Eastern Mediterranean river and coastal wetlands	Maria Tzortziou
Field campaign/measurements in the Chesapeake Bay coastal wetlands	Maria Tzortziou
Nantucket paleoclimate – coring bogs and marshes	Dorothy Peteet
Norway-USA International Polar Year Traverse of East Antarctica, 2008-2009	Thomas Neumann
Windless Bight field work, Antarctica	Robert Bindschadler

Field campaigns where scientists in the Division were Co-Principal Investigators in FY2009

Field Campaign	Co-Principal Investigator
Hudson River estuary marshes paleoenvironment	Dorothy Peteet
Seven SouthEast Asian Studies Mission, Singapore MPLNET site	Ellsworth Welton
TIGERZ-II field campaign in India, Kanpur MPLNET site	Ellsworth Welton

Field campaigns where scientists in the Division were Co-Investigators in FY2009

Field Campaign	Co-Investigator
Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)	Ralph Kahn
Australian Arid Zone (Simpson Desert)	Edward Kim
International instrument inter-comparison campaign for trace gas measurements in the Netherlands	Maria Tzortziou

Workshops Convened by ESD Scientists in FY2009

Workshop	Organizer
Air Quality Workshop at Aura Science Team Meeting, Leiden, Netherlands	Bryan Duncan
American Meteorological Society (AMS) 34th Radar Meteorology Conference	Gerald Heymsfield
Atmospheric Science Precipitation Science Session (AS1.3), European Geosciences Union General Assembly, Vienna, Austria	Arthur Hou (co-Convener)
Glory Mission Science Team Meeting, New York	Michael Mishchenko
Institute of Electrical and Electronics Engineers (IEEE) Aerospace 2009, Architecture and Data Management in the Global Earth Observation System of Systems (GEOSS)	Kathy Fontaine
Institute of Electrical and Electronics Engineers (IEEE) Aerospace 2009, System of Systems Engineering	Kathy Fontaine
West Antarctic Ice Sheet workshop	Robert Bindschadler

Appendix F. Professional Activities, Honors, and Awards

Members of Academies

Academy	Name
National Academy of Engineering	Claire Parkinson
National Academy of Sciences	James Hansen

Fellows of Professional Societies

Society	Name
American Association for the Advancement of Science	Franco Einaudi Cynthia Rosenzweig James A. Smith
American Geophysical Union	Robert Bindschadler Anne Douglass James Hansen William Lau Charles McClain Michael Mishchenko Richard Stolarski Compton Tucker Warren Wiscombe
American Meteorological Society	Anne Douglass Robert Cahalan Anthony Del Genio Franco Einaudi James Hansen Randal Koster William Lau Michael Mishchenko Claire Parkinson Eric A. Smith Wei-Kuo Tao Warren Wiscombe
American Society of Agronomy	Cynthia Rosenzweig
Institute of Electrical and Electronics Engineers	David Le Vine James A. Smith
International Association of Geomagnetism and Aeronomy	Charles Jackman
International Society for Optical Engineering (SPIE)	James A. Smith
Optical Society of America	Michael Mishchenko
Paul Brandwein Institute For Science Education	Elissa Levine
Royal Meteorological Society	Franco Einaudi

ESD Scientists that are Goddard Senior Fellows

Robert Bindschadler
James Hansen
Claire Parkinson
James A. Smith
Compton Tucker

Goddard Senior Fellows form a very small group of individuals selected for their contributions to science, engineering, and technology.

Members of Committees of Professional Societies in FY2009

Society	Committee Name	Member
American Association for the Advancement of Science	AAAS Council	Claire Parkinson
American Association for the Advancement of Science	AAAS Science Journalism Awards Screening Committee	Claire Parkinson
American Geophysical Union	AGU Technical Committee on Precipitation	Eyal Amitai
American Geophysical Union	Fellows Committee, Atmospheric Sciences Section	Michael Mishchenko
American Geophysical Union	Hydrology Remote Sensing Technical Committee	Matthew Rodell
American Geophysical Union	Hydrology Section Fall Program Committee	Matthew Rodell
American Meteorological Society	Atmospheric Radiation Committee	Lazaros Oreopoulos
American Meteorological Society	Mesoscale Processes Committee	Scott Braun
American Meteorological Society	Radar Meteorology Committee	Gerald Heymsfield
American Society of Limnology and Oceanography	Meetings Committee	Maria Tzortziou
Committee on Space Research	Commission A (Earth Observation), Vice-Chair	Ralph Kahn
Coordination Group on Meteorological Satellites	International Precipitation Working Group	George Huffman
Group on Earth Observations	Precipitation Task	George Huffman
New York City Audubon Society	Board of Directors, Conservation Committee	Dorothy Peteet
World Climate Research Programme Global Water and Energy Cycle Experiment	Global Land Atmosphere System Study (panel	Rolf Reichle

Editorships of Professional Journals in FY2009

Journal	Editor
Atmospheric Measurement Techniques	Joanna Joiner (Executive Editor)
Journal of Glaciology	Robert Bindschadler
Journal of Quantitative Spectroscopy and Radiative Transfer	Michael Mishchenko

Associate Editorships of Professional Journals in FY2009

Journal	Associate Editor
Advances in Adaptive Data Analysis	Steven Long (Assistant Editor)
Atmospheric Chemistry and Physics	Bryan Duncan
IEEE Geoscience and Remote Sensing Letters	Edward Kim
Journal of Geophysical Research-Atmospheres	Steven Platnick
Journal of Hydrometeorology	George Huffman
Kinematics and Physics of Celestial Bodies	Michael Mishchenko
Monthly Weather Review	Scott Braun
Polar Research	Sirpa Hakkinen
The Cryosphere	Dorothy Hall
Waves in Random and Complex Media	Michael Mishchenko

Editors of Special Issues in FY2009

Name of Special Issue	Editor
6^{th} Edition of the CD-ROM UV/Vis Spectra Data Base	David Lary
Deep Sea Research II, Atlantic Meridional Overturning Special Issue	Sirpa Hakkinen (co-Editor)
UV/Vis+ Spectra Data Base (UV/Vis+ Photochemistry Database)	David Lary

List of GSFC Awards Received in CY2009

GSFC Award	Recipient
Excellence in Information Science and Technology	Curt Tilmes
Exceptional Achievement for Engineering	John Sonntag (EG&G)
Exceptional Achievement for Outreach	Brian Campbell (SAIC)
Exceptional Achievement for Science	Marc Imhoff
Exceptional Achievement for Science	Nickolay Krotkov (UMBC)
Exceptional Achievement for Secretarial/Clerical	Omega Williams
Leadership Award	Jose Rodriguez
Quality and Process Improvement Individual	Blanche Meeson
Robert H. Goddard Award of Merit	Richard Stolarski
William Nordberg Memorial Award for Earth Science	William Krabill

List of NASA Honor Awards Received in CY2009

NASA Award	Recipient
Exceptional Achievement Medal	Jay Zwally
Exceptional Achievement Medal	Robert Wolfe
Exceptional Scientific Achievement Medal	Anne Douglass
Exceptional Service Medal	Dorothy Hall
Exceptional Service Medal	Jack Richards
Exceptional Service Medal	James Irons
Exceptional Service Medal	Matthew McGill
Group Achievement Award	OMI Instrument Team
Outstanding Leadership Medal	David Starr
Outstanding Leadership Medal	Shahid Habib
Public Service Group Achievement Award	Science Outreach Team

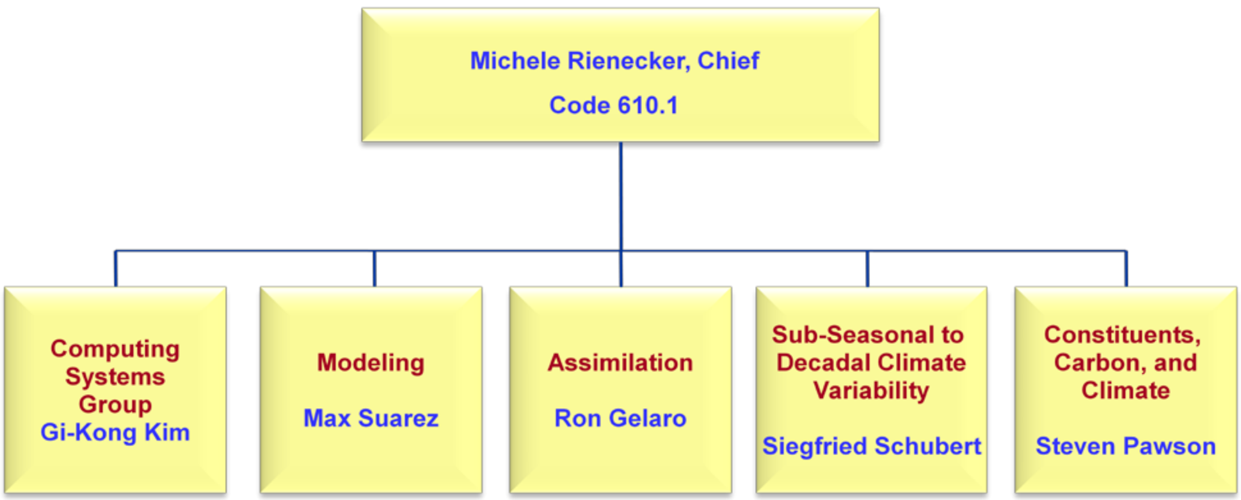
List of National and International Honors and Awards Received in CY2009

National and/or International Awards	Recipient
AGU Yoram J. Kaufman Unselfish Cooperation in Research Award	Ralph Kahn
Carl Gustaf Rossby Research Medal (AMS)	James Hansen
Distinguished Alumni of the University of Hong Kong	William Lau
Environmental Protection Agency Ozone Layer Protection Award	Paul Newman
Excellence in Federal Career Award	Claire Parkinson
Finalist for Service to America Medal (one of 30)	Compton Tucker

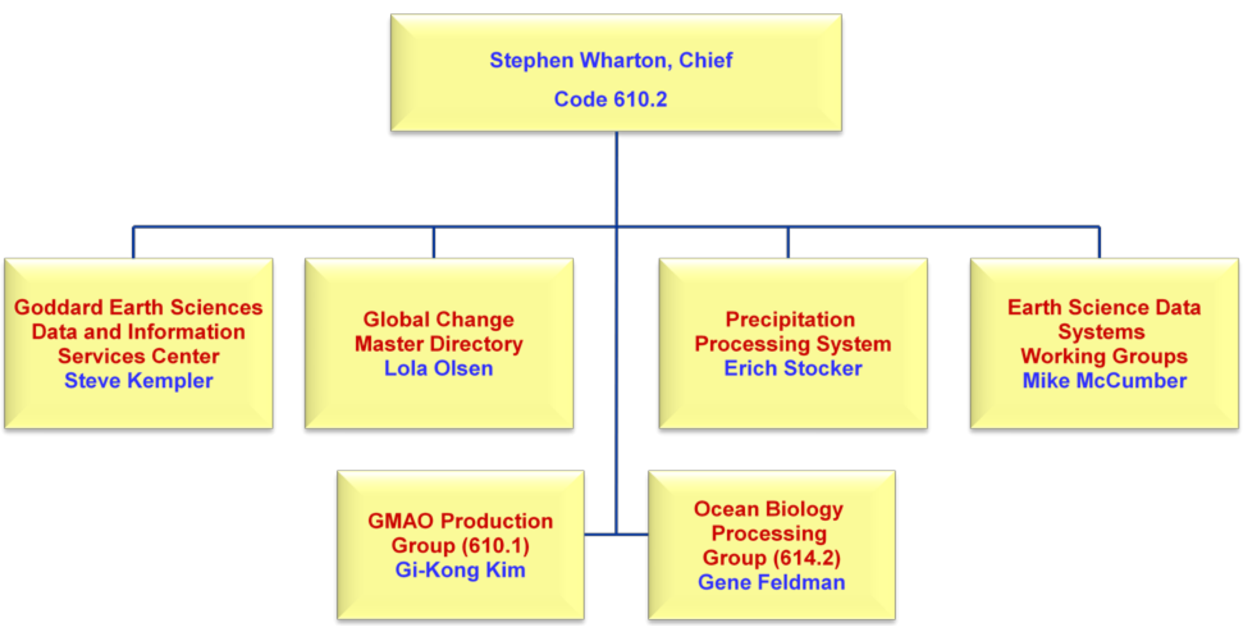
Appendix G. The Organizational Structure of the Division's Laboratories and Offices

Note: Code 610.4 and 611 will not be addressed here since they have no branch structure.

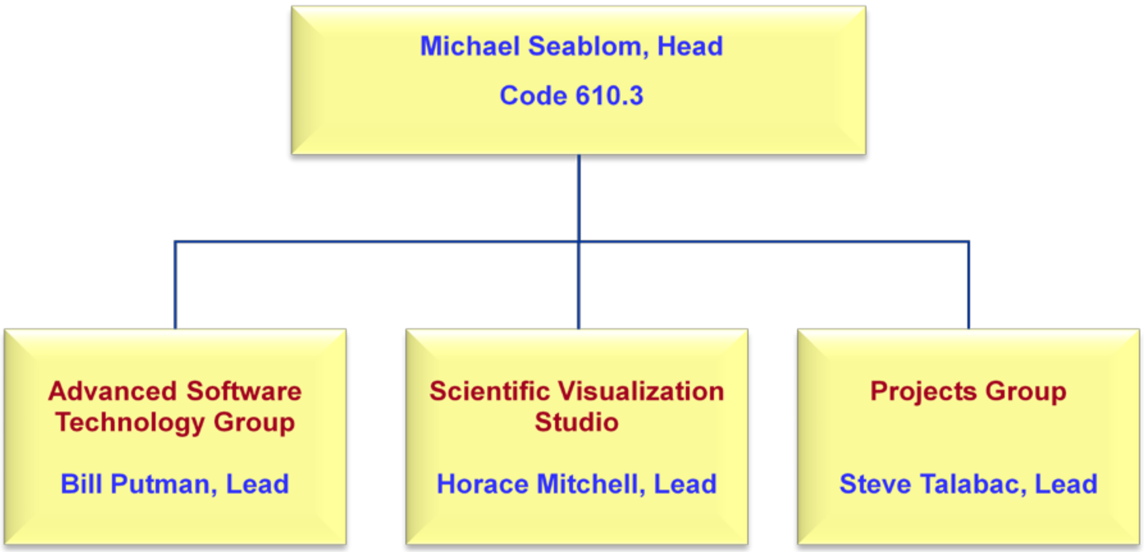
Global Modeling and Assimilation Office, Code 610.1



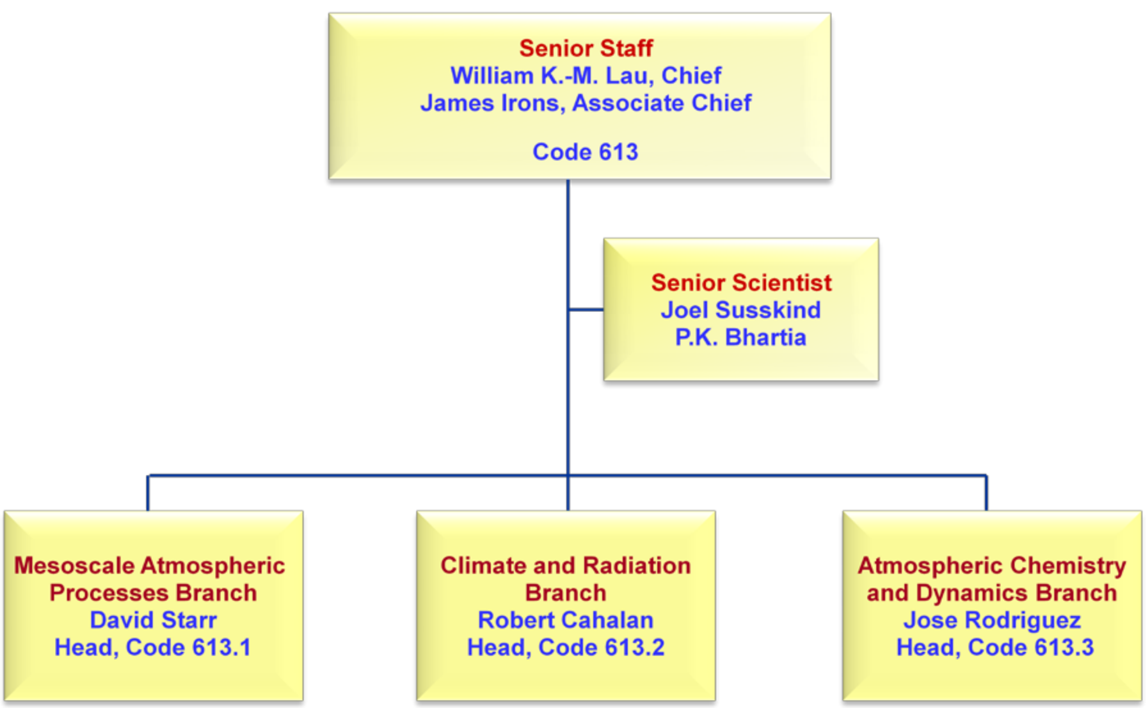
Global Change Data Center, Code 610.2



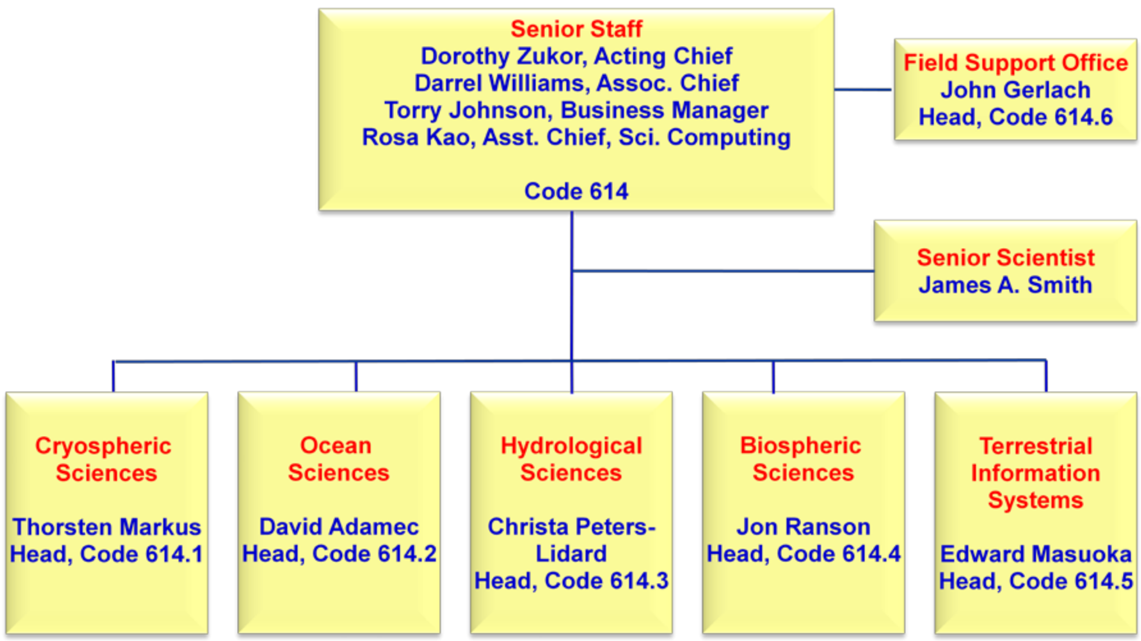
Software Integration and Visualization Office, Code 610.3



Laboratory for Atmospheres, Code 613

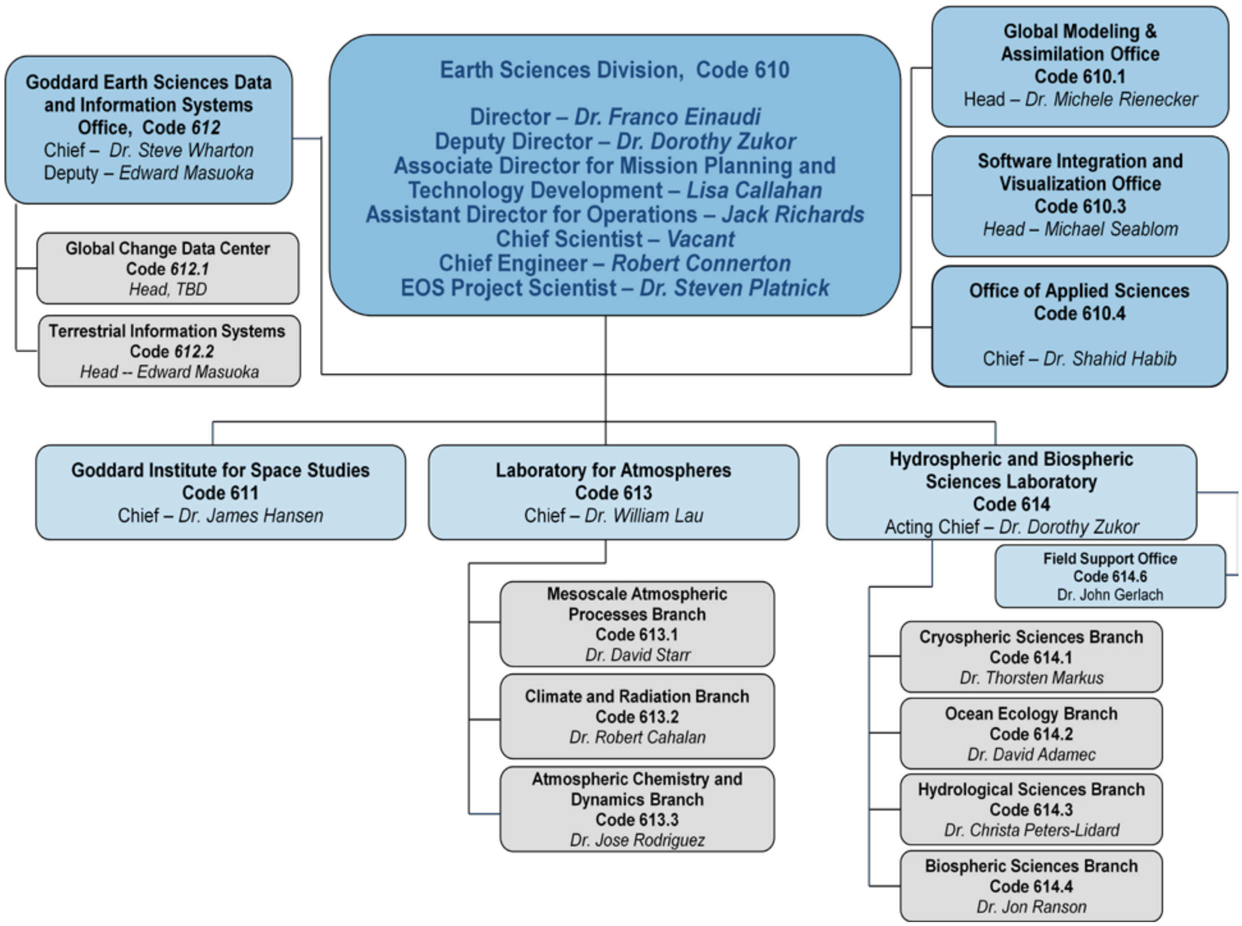


Hydrospheric and Biospheric Sciences Laboratory, Code 614



Earth Sciences Division

(Shown with future reorganizations currently in process)



Appendix H. Acronyms

3D-Winds	Three-Dimensional Tropospheric Winds from Space-based Lidar
4D-var	4 dimensional variational
AAAS	American Association for the Advancement of Science
AAMP	Auroral Acceleration Multiprobe
ABET	Accreditation Board for Engineering and Technology
ACAM	Airborne Compact Atmospheric Mapper
ACDB	Atmospheric Chemistry and Dynamics Branch
ACE	Aerosol-Cloud-Ecosystem mission
ACE	Aerosol Characterization Experiments
ACM SIGGRAPH	Association for Computing Machinery Special Interest Group on Graphics and Interactive Techniques
ADAM	Aeronomy and Dynamics at Mars
AeroCenter	Goddard Center of Excellence in Aerosol Research
AERONET	AERosol RObotic NETwork
AESMIR	Airborne Earth Sciences Microwave Imaging Radiometer
AGCM	Atmospheric General Circulation Model
AGU	American Geophysical Union
AIM	Aeronomy of Ice in the Mesosphere
AIRS	Atmospheric Infrared Sounder
AMS	American Meteorological Society
AMSR-E	Advanced Microwave Scanning Radiometer-Earth Observation System
AMSU	Advanced Microwave Sounding Unit
APS	Aerosol Polarimeter Sensor
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
ARM	Atmospheric Radiation Measurement
ASCENDS	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
ASPRS	American Society of Photogrammetry and Remote Sensing
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTG	Advanced Software Technology Group
ATIP	Advanced Technology Initiatives Program
ATL	Aerosol and Temperature Lidar
ATMS	Advanced Technology Microwave Sounder
A-Train	Afternoon Satellite Constellation
AVDC	Aura Validation Data Center
AVHRR	Advanced Very High Resolution Radiometer
AWC	Atmospheric Water Cycle
B&P	Bid and Proposal
BrO	Bromine Monoxide
BUV	backscatter ultraviolet
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CARB	California Air Resources Board
CARPE	Central African Regional Program for the Environment
CBLAST	Coupled Boundary Layers Air/Sea Transfer
CCM	Chemistry Climate Model
CCMC	Community Coordinated Modeling Center
CCRI	Climate Change Research Initiative
CCIR-NY	Climate Change Information Resource, New York
CCSP	Climate Change Science Plan
CDC	Center for Disease Control
CEAS	Center for Earth-Atmospheric Studies
CERES	Clouds and the Earth’s Radiant Energy System

CHOCHO	Glyoxal
CIMSS	Cooperative Institute of Meteorological Satellite Studies
CLAIM-3D	3D Cloud-Aerosol Interaction Mission
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLIVAR	WCRP project on International Research Program on Climate Variability and Predictability
CLM	Community Land Model
CLPP	Cold Land Processes Pathfinder
CLPX	Cold Land Processes Experiment
CM&O	Center Management and Operation
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COMMIT	Chemical Optical and Microphysical Measurements of In-Situ Troposphere
CoSMIR	Conically Scanning Millimeter-wave Imaging Radiometer
COSPAR	Committee on Space Research
CoSSIR	Conical Scanning Submillimeter-wave Imaging Radiometer
CPU	Central Processing Unit
CrIS	Crosstrack Infrared Sounder
CSTEA	Center for the Study of Terrestrial and Extraterrestrial Atmospheres
CSU	Colorado State University
CTM	Chemical Transport Model
CZCS	Coastal Zone Color Scanner
DAAC	Distributed Active Archive Center
DAO	Data Assimilation Office
DAS	Data Assimilation System
DDF	Director's Discretionary Fund
DESDynI	Deformation, Ecosystem Structure, and Dynamics of Ice
DISC	Data and Information Services Centers
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DOE	Department of Energy
ECMWF	European Center for Medium-range Weather Forecasting
EDC	Eros Data Center
EdGCM	Educational Global Climate Models
EDOP	ER-2 Doppler radar
EnKF	Ensemble Kalman Filter
ENSO	El Niño/Southern Oscillations
ENVISAT	ENVIronment SATellite
EO-1	Earth Observing-1
EOS	Earth Observing System
EOSDIS	Earth Observing System (EOS) Data and Information System
EP TOMS	Earth Probe Total Ozone Mapping Spectrometer
EPA	Environmental Protection Agency
EPO	Education and Public Research
EPRI	Electric Power Research Institute
ERB	Earth Radiation Budget
ERBE	Earth Radiation Budget Experiment
EROS	Earth Resources Observation and Science
ES LOB	Earth Science Line of Business
ESA	European Space Agency
ESD	Earth Sciences Division
ESDIS	Earth Science Data and Information System
ESMF	Earth System Modeling Framework
ESPD	Earth Science Projects Division
ESSIC	Earth System Science Interdisciplinary Center
ESSP	Earth System Science Pathfinder

EUV	extreme ultraviolet
EV	Earth Venture
FAO	United Nations Food and Agriculture Organization
FAS	Foreign Agriculture Service
FCA	Full Cost Accounting
FTE	Full Time Equivalent
FWS	Fish and Wildlife Service
GACM	Global Atmospheric Composition Mission
GACP	Global Aerosol Climatology Project
GCDC	Global Change Data Center
GCE	Goddard Cumulus Ensemble
GCMD	Global Change Master Directory
GCMs	General Circulation Models
GCOM-W	Global Change Observation Mission-Water
GCSS	Global Energy and Water Cycle Experiment's Cloud System Study
GEIS	Global Emerging Infections Surveillance and Response Program
GEO	Geosynchronous/Geostationary Earth Orbit
GEOCAPE	Geostationary Coastal and Air Pollution Events
GEOS	Goddard Earth Observing System
GEOS CCM	Global Earth Observing System Chemistry Climate Model
GEOSS	Global Earth Observation System of Systems
GES	Goddard Earth Science
GES	Goddard Earth Sciences
GEST	Goddard Earth Sciences and Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GFO	GeoSat Follow-On
GHG	Greenhouse Gases
GHRSST	Global High Resolution Sea Surface Temperature
GIS	Geographic Information System
GISS	Goddard Institute for Space Sciences
GLACE	Global Land-Atmosphere Coupling Experiment
GLAS	Geoscience Laser Altimeter System
GLASS	Global Land Atmosphere System Study
GLDAS	Global Land Data Assimilation System
GloPac	Global Hawk Pacific experiment
GMAO	Global Modeling and Assimilation Office
GMI	Global Modeling Initiative
GOCART	Goddard Global Ozone Chemistry Aerosol and Radiation Transport
GOES	Geostationary Operational Environmental Satellite
GoHFAS	Goddard Howard University Fellowship in Atmospheric Sciences
GOME	Global Ozone Monitoring Experiment
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GRACE	Gravity Recovery and Climate Experiment
GRIP	Genesis and Rapid Intensification Processes
GSFC	Goddard Space Flight Center
GSI	Grid-point Statistical Interpolation
H_2O	Water
HALOE	Halogen Occultation Experiment
HCHO	Formaldehyde
HIRS	High Resolution Infrared Sounder
HQ	Headquarters
HS3	Severe Storm Sentinel Mission
HU	Howard University
HyspIRI	Hyperspectral/IR Imager

ICESat	Ice, Cloud, and Land Elevation Satellite
IEEE	Institute of Electrical and Electronics Engineers, Inc
IGARSS	Institute of Electrical and Electronics Engineers, Inc (IEEE) Geoscience and Remote Sensing Society
iGETT	Integrated Geospatial Education and Technology Training Project
IIP	Instrument Incubator Program
InSAR	Interferometric Synthetic Aperture Radar
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IR	Infrared
IRAD	Internal Research and Development
ISCCP	International Satellite Cloud Climatology Project
ISS	International Space Station
IT	Information Technology
JAMEX	ACE-Asia, Joint Aerosol Monsoon Experiment
JAXA	Japan Aerospace Exploration Agency
JCES	Joint Center for Earth Science
JCET	Joint Center for Earth Systems Technology
JCSDA	Joint Center for Satellite Data Assimilation
JIESIC	Joint Interdisciplinary Earth Science Information Center
JPL	Jet Propulsion Laboratory
K-12	Kindergarten to Grade 12
LAADS	MODIS L1 and Atmospheres Archive and Distribution System
LaRC	Langley Research Center
LASCO/SOHO	Large Angle Spectrometric Coronograph/Solar Heliospheric Observatory
LDAS	Land Data Assimilation System
LDCM	Landsat Data Continuity Mission
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LEO	Low Earth Orbit
LIS	Land Information System
LIS	Lightning Imaging Sensor
LIST	Lidar Surface Topography
LOB	Line of Business
LPSO	Landsat Project Science Office
MAG/ACE	Magnetometer/Advanced Composition Explorer
MC	Magnetospheric Constellation (MagCon)
MENA	Middle East and North Africa
MERRA	Modern Era Retrospective-Analysis for Research and Applications
MESSENGER	MErcury Surface, Space ENvironment, GEeochemistry, and Ranging
MISR	Multi-angle Imaging SpectroRadiometer
MLS	Microwave Limb Sounder
MODAPS	Moderate Resolution Imaging Spectro-radiometer (MODIS) Data Processing System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOLA	Mars Orbiter Laser Altimeter
MOS	Modular Optoelectronic Scanner
MOUs	Memorandums of Understanding
MPLNET	Micropulse Lidar Network
MU-SPIN	Minority University-SPace Interdisciplinary Network
NAS	NASA Advanced Supercomputing
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBO	New Business Office
NBRP	New Business Review Panel
NCAR	National Center for Atmospheric Research
NCCS	NASA Center for Computational Sciences

NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NDACC	Network for the Detection of Atmospheric Chemical Change
NEO	NASA Earth Observations
NESDIS	National Environmental Satellite Data and Information Service
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NOVICE	Newly-Operating and Validated Instruments Comparison Experiments
NPOESS	National Polar-orbiting Operational Environmental Satellite System
N-POL	NASA Polarization radar
NPP	NASA Postdoctoral Program
NPP	NPOESS Preparatory Project
NPS	National Park Service
NRA	NASA Research Announcement
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSIPP	NASA Seasonal to Interannual Prediction Project
NSTA	National Science Teachers Association
NWP	Numerical Weather Prediction
O_3	Ozone
OCDSPS	Ocean Color/SST Data Processing System
OCEaNS	Ocean Carbon Ecosystems and Near-Shore
OCTS	Ocean Color and Thermal Scanner
ODS	Ozone Depleting Substance
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
ORCA	Ocean Remote Chemical/optical Analyzer
OSEs	Observing System Experiments
OSSEs	Observing System Simulation Experiments
PAC3E	Pacific Atmospheric Composition, Cloud, and Climate Experiment
PAO	Public Affairs Office
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
PATH	Precipitation and All-weather Temperature and Humidity
PEATE	Product Evaluation and Algorithm Test Element
PECASE	Presidential Early Career Award for Scientists and Engineers
PI	Principal Investigator
PMM	Precipitation Measuring Missions
POAM	Polar Ozone and Aerosol Measurement
POES	Polar Operational Environmental Satellite
POETRY	Public Outreach, Education, Teaching, and Reaching Youth
POLDER	POLarization and Directionality of the Earth's Reflectance
PPS	Precipitation Processing System
PUMAS	Practical Uses of Math And Science
QWIPS	Quantum Well Infrared Photodectors
R&A	Research and Analysis
RDMS	Research and Development Multiple Support
ROSES	Research Opportunities in Space and Earth Sciences
RRAP	Resident Research Associateship Program
RRS	Rapid Response System
SAGE	Stratospheric Aerosol and Gas Experiment
SAR	Synthetic Aperture Radar
SBIR	Small Business Innovative Research
SBUV	Solar Backscatter Ultraviolet

SCIAMACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric ChartographY
SCLP	Snow and Cold Land Processes
SDPS	Sea-viewing Wide Field of view Sensor (SeaWiFS) Data Processing System
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SED	Sciences and Exploration Directorate
SEPOF	Science Education and Public Outreach
SERVIR	Spanish for “to serve”
SHADOZ	Southern Hemisphere Additional Ozonesondes
SIESIP	Seasonal to Interannual Earth Science Information and Partners
SIMBIOS	Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies
SIR-C	Spaceborne Imaging Radar
SIRICE	Submillimeter and Infrared Ice Cloud Experiment
SIVO	Software Integration and Visualization Office
SMAP	Soil Moisture Active Passive
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMD	Science Mission Directorate
SMM/I	Special Sensor Microwave/Imager
SMMR	Scanning Multichannel Microwave Radiometer
SNR	Signal to Noise Ratio
SO_2	Sulfur Oxides
SOHO	Solar and Heliospheric Observatory
SORCE	Solar Radiation and Climate Experiment
SPIE	International Society for Optical Engineering
SPOT	Système Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
SSBUV	Shuttle Solar Backscatter Ultraviolet
SST	Sea Surface Temperature
STROZ-LITE	Stratospheric Ozone Lidar Trailer Experiment
SUNBEAMS	Students United with NASA Becoming Enthusiastic About Math and Science
SVS	Scientific Visualizations Studio
SWBs	Solar Weather Buoys
SWE	Snow Water Equivalent
SWEPAM/ACE	Solar Wind Electron, Proton and Alpha Monitor/Advanced Composition Explorer
SWOT	Surface Water and Ocean Topography
TC^4	Tropical Composition, Cloud, and Climate Coupling Experiment
TCSP	Tropical Cloud Systems and Processes
TES	Troposphere Emission Spectrometer
THORPEX	The Observing System Research and Predictability Experiment
TIROS	Television Infrared Observation Satellites
TMI	TRMM Microwave Imager
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean TOPography EXperiment
TOVS	NOAA’s TIROS Operational Vertical Sounder
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measuring Mission
TSDIS	Tropical Rainfall Measuring Mission (TRMM) Science Data and Information System
TTL	tropical tropopause transition layer
TWC	Terrestrial Water Cycle
UARS	Upper Atmosphere Research Satellite
UAS	Unmanned Aircraft System

UMBC	University of Maryland at Baltimore County
UMCP	University of Maryland at College Park
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNH	University of New Hampshire
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
UV	Ultraviolet
UV-B	Ultraviolet-B
UW	University of Wisconsin
VAL	Visualizations Analysis Laboratory
VCL	Vegetation Canopy Lidar
VEG	Vegetation
VIC	Variable Infiltration Capacity model
VIRS	Visible and Infrared Scanner
VIIRS	Visible Infrared Imager Radiometer Suite
VIS IR	Visible Infrared
VITAL	Visual and Technical Arts Lab
WHO	World Health Organization
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WWRP	World Weather Research Programme